Spectrum Management for the VLBI Global Observing System (VGOS) Observations

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Abstract The wideband receiving system for 2–14 GHz of the VLBI Global Observing System (VGOS) challenges the spectrum management and the interference investigations. We share our experience with the new VGOS telescope, built at the Metsähovi Geodetic Research Station, as well as the long term experience of Aalto University Metsähovi Radio Observatory with spectrum management and radio interference monitoring. The following steps and measures should be made: (1) the registration of the VGOS site at the International Telecommunication Union – Radio Section to get a legal position for a radio astronomy site; (2) intentions to claim a protection zone for a RAS site; (3) possibilities of avoiding RFI; (4) an interference monitoring system to track the changes of the electromagnetic environment and eventually to give notice to the national spectrum administration, if unwanted RFI is detrimental to VLBI observations.

Keywords VGOS, RFI, spectrum management, spectrum allocation, interference monitoring, ITU-R registration

1 Introduction

VLBI Global Observing System (VGOS) is a passive user of the frequency range of 2–14 GHz. Active transmissions, e.g., by telecommunication such as 5G that has allocated frequency bands, cause interference and a conflict of interest when detrimental radiation disturbs the radio astronomy and VGOS observations. The Radio Astronomy Service (RAS) has only about 250 MHz of allocated bandwidth in the VGOS range, but VGOS uses four frequency blocks with eight channels each of 32 MHz bandwidth summing up to a demand of at least 1,024 MHz of bandwidth. In Table 1, the current IVS VGOS frequency band setups are shown. This causes various challenges for VGOS observations. More difficulties bring out the fact that the trial phase of experiencing different frequency sequences is ongoing and that the VGOS community has no clear consensus on the final frequency setup. Taking into account the general frequency allocation, it appears not to be realistic for VGOS to demand its own allocation for all VGOS channels. That is why striving for alternative protection methods is necessary. Local radio quiet zones (RQZ) are one possibility for getting protection for VGOS sites. However, in most cases the separation distances could be hundreds of kilometers, which cannot be achieved in populated areas. An important aspect is continuous radio frequency interference (RFI) monitoring, to track the ongoing changes of the electromagnetic environment and eventually give notice of RFI incidence detrimental to VGOS observation to the national spectrum administration. For the awareness of the VGOS requirements a fluent dialogue between the VGOS operator and the national frequency administration is required. In any case, it is also very important that each national administration register the VGOS sites at the International Telecommunication Union – Radio Section (ITU-R); thus the site will get a legal position as a radio astronomy service site. The registration improves possibilities of achieving acknowledgement by regulators and active services. In this paper, we

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present some administrative spectrum management aspects and practical examples of RFI issues observed in Aalto University's Metsähovi Radio Observatory. Figure 1 shows the current frequency allocations among the different services between 2,500 and 5,000 MHz in Finland. This figure indicates the potential sources of disturbance of VGOS observations.

2 ITU Registration, Band Allocation, Protection Zones

The ITU-R (International Telecommunication Union – Radiocommunication Sector) main mission is to facilitate seamless and interference-free operation of radio communication services between member states. In other words, the ITU-R's main role is to coordinate the use of radio frequency spectrum and satellite orbit resources by the development of standards and regulations for radiocommunication systems with the objective of ensuring their effective use. ITU-R has recognized services such as RAS. This gives RAS an equal position to any other (active) service. Therefore, other radio spectrum users have to respect the requirements of frequencies allocated to RAS. Each radio service could have either primary or secondary allocations. In the case of RAS, the primary frequency allocation usually means that all transmissions are prohibited. The secondary allocation means that all practical steps must be done to protect RAS from harmful interference. However, there is only a limited number of RAS allocations. For instance, in a VGOS operation range there is only a total of about 250 MHz accumulated bandwidth allocated to RAS. This is a big challenge for VGOS operation as its frequency setup is not following the radio astronomy method of spectral line observations, but needs at least 1,024 MHz bandwidth in order to achieve millimeter accuracy for global reference frames.

Each observatory should be registered through its national administration to the ITU-R database. The initiative must come from the VGOS station owner. The registration contains the geographical location and the receiving capabilities. This is a first step for protection. The observatory is then listed officially as a RAS station and recognized as a passive user of radio spectrum. It is important to register as early as possible, as only future allocations or licenses will have to respect the VGOS site. For instance, future space mission owners may consult the ITU-R database to identify downlink areas avoiding illuminations of RAS sites.

The most effective protection which could be achieved would be VGOS' own frequency allocation either on the international or the national level. A more realistic option would be to achieve protection on the national level. For example, a public administration in Germany is tasked to perform contributions to the global geodetic tasks (VGOS observations), and therefore the frequency administration has to provide protection of the VGOS site when new licenses are emitted. Unfortunately, many VGOS sites are in another legal position. In general, VGOS' own frequency allocations would be best, but almost not achievable. For practical reasons it appears more likely to demand for the globally distributed VGOS network stations protection zones around the observatories, so that they can do their duties in an undisturbed manner. For instance, the RQZ concept is a rather effective method for protecting observations at maximum [1, 2] and is recommended wherever it is possible. The next alternative with fewer restrictions would be a coordination zone around VGOS sites, in which the regulators could introduce restrictions and conditions for other services in order to provide protection of the VGOS sites.

3 Interference Monitoring

The Aalto University Metsähovi Radio Observatory (MRO) has conducted continuous RFI monitoring for over 20 years. The monitoring covered especially the range of 500–1,000 MHz (often used as an intermediate frequency band) but also the S-band (2–2.5 GHz) used by legacy geodetic VLBI. In Figure 2, a typical radio spectrum between 400–2,400 MHz is shown. It was recorded with MRO's RFI monitoring system, which consists of a turnable log-periodic antenna, a pre-amplifier, and a backend. Ettus USRP N210 Software Defined Radio (SDR) is used as a backend. With the current instrumentation it is also possible to perform RFI monitoring in some narrower bands up to around 12 GHz. This is of special interest for first studies on the impact of various satellite services (e.g., geo-stationary satellites and OneWeb/StarLink satellite

Table 1 The current IVS VGOS frequency band setups. The individual channels have a width of 32 MHz. The values shown in the table are the upper edges of frequencies.

Band A	3032.4 MHz	3064.4 MHz	3096.4 MHz	3224.4 MHz	3320.4 MHz	3384.4 MHz	3448.4 MHz	3480.4 MHz
Band B	5272.4 MHz	5304.4 MHz	5336.4 MHz	5464.4 MHz	5560.4 MHz	5624.4 MHz	5688.4 MHz	5720.4 MHz
Band C	6392.4 MHz	6424.4 MHz	6456.4 MHz	6584.4 MHz	6680.4 MHz	6744.4 MHz	6808.4 MHz	6840.4 MHz
Band D	10232.4 MHz	10264.4 MHz	10296.4 MHz	10424.4 MHz	10520.4 MHz	10584.4 MHz	10648.4 MHz	10680.4 MHz

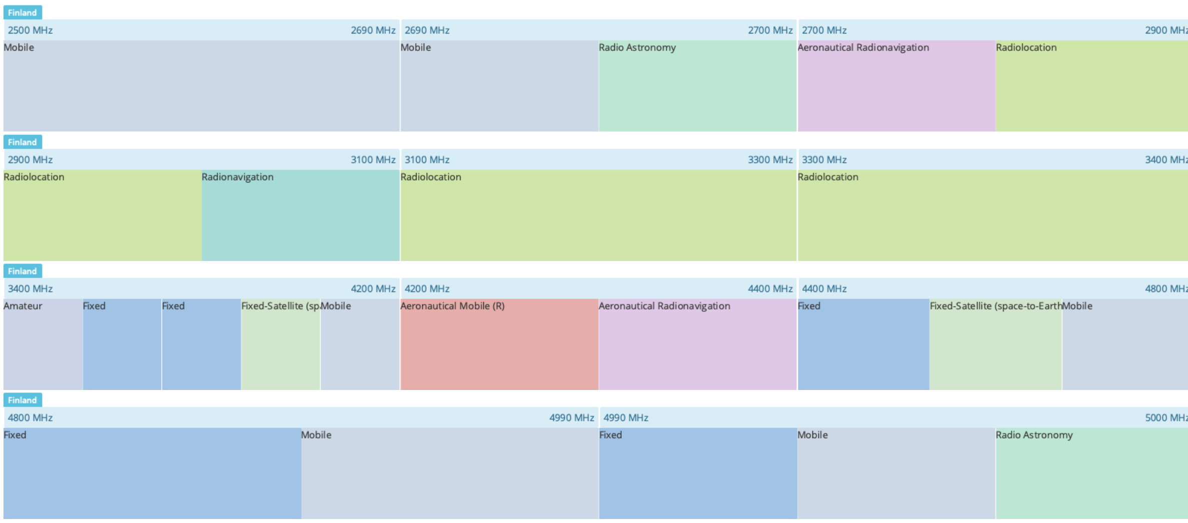

Fig. 1 The frequency allocation between 2500 and 5000 MHz in Finland.

service at 10.7–11.7 GHz) on radio astronomy or on broadband geodetic VLBI [3].

A dedicated RFI monitoring system that covers the VGOS broadband frequency range is developed at the Metsähovi Geodetic Research Station. It will allow us to detect harmful signals in real-time and take possible actions.

Geodetic VLBI observations in the legacy S-band (2,100–2,390 MHz) seriously suffer from active transmitters in many locations (seen also in Figure 2), such as mobile and military services. At higher VGOS frequencies (ca. 5–10 GHz), a new interference threat is the 5G cellular network. Various satellite mega constellations such as OneWeb or StarLink could be major problems for passive services in the future. In this decade we will see the launch of thousands of small satellites in low Earth orbits for communication [4]. In this scenario, it is very likely that satellites passing the radio telescope's beam will generate RFI. It is frightening that the satellite's transmission power could be so strong that the low noise amplifiers (LNA) of the radio astronomy receiver could be saturated. Figure 3 shows the spectrum of MRO's 1.8-meter solar telescope when a OneWeb satellite passes its beam. The power level rises more than 10 dB when the satellite passes the telescope's beam. This is a major interference noise contribution, and any kind of radio astronomical observation of faint extra-galactic radio sources will not be possible when such interference is present.

Another important aspect in interference monitoring and protection is a self-generated RFI inside the observatory. This is an increasing problem exposed by low-cost electronic devices, which can be found also in the observatories. The lower cost, unfortunately, means also less consideration to EMI (Electromagnetic interference) and EMC (Electromagnetic compatibility) issues. For instance, a single missing capacitor in the power feed could cause interference which is seen in the radio spectrum.

When executing RFI monitorings, the calibration of the system is an important issue. The readings from the spectrum analyzer give a first clue on signal strength. However, the parameters of the whole monitoring system chain should be known including system total gain and possible losses in RF cables. The calibrated RFI monitoring values should be compared with the ITU-R threshold interference level. The accepted threshold interference levels for the radio astronomy service bands

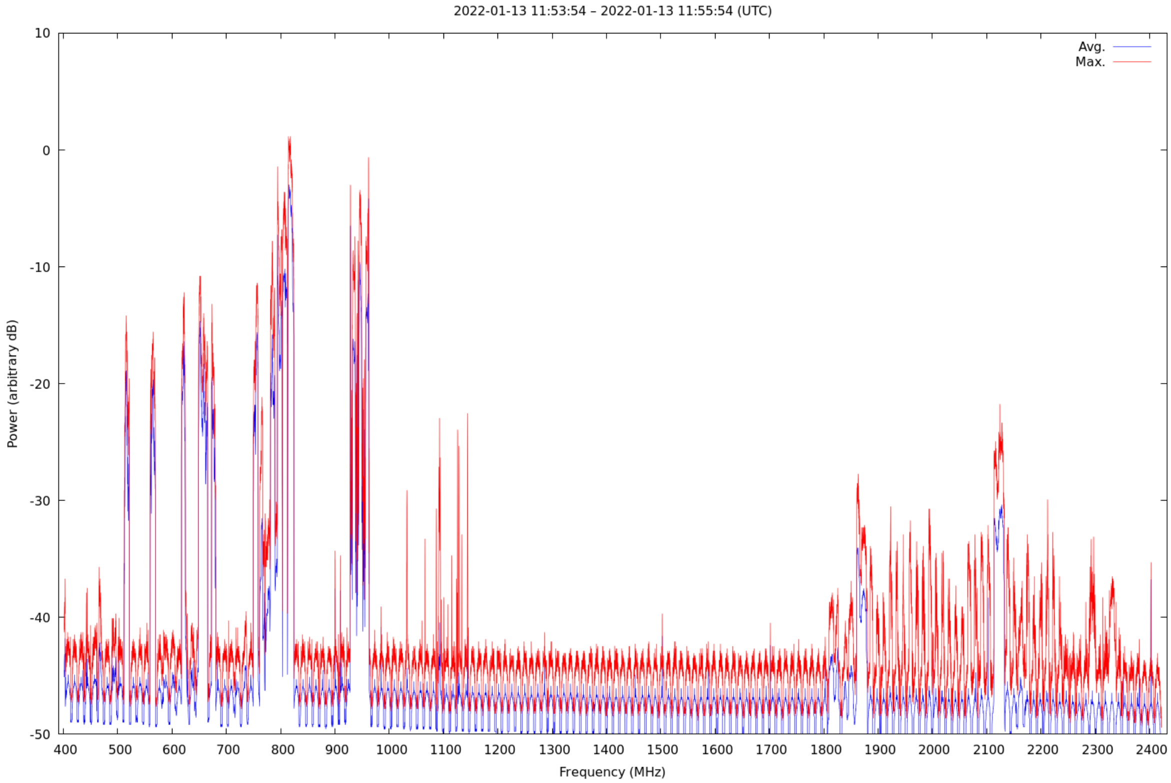

Fig. 2 The radio spectrum between 400 and 2,400 MHz. The spectrum has been observed by MRO's dedicated interference monitoring system. The spectrum clearly shows TV broadcasts and mobile telephone services (900 MHz and 18,000 MHz). The frequency band above 2 GHz is heavily used by active transmitters, which makes it almost impossible to execute undisturbed radio astronomy observations.

are presented in Recommendation ITU-R RA.769-2: Protection criteria used for radio astronomical measurements. This recommendation gives threshold interference levels of both continuum and VLBI observations [5].

4 Mitigation Methods

Besides spectrum management, there are also other mitigation methods to protect observations against harmful interference. There are several technical solutions such as additional notch filters in the receiver and software filters in the data post-processing phase either in the local recording or data correlation process. However, none supplies a perfect solution. The notch filter is not an optimal solution if several bands must be filtered out. Even increasing the dynamical range of the LNA may have an effect on its sensitivity. The best possible technical solution would be probably a combination of several mitigation techniques. Besides technical mitigation approaches, an operational approach for mitigation is the scheduling of the observations. Static scheduling considers a horizon mask where (terrestrial) interferers are excluded. Dynamic scheduling considers satellite orbits. The question remains whether this can be handled if many thousands of orbits have to be considered. Finally, an obvious method is to use only frequencies which are free from interference. However, the interference situation varies between different observatories/countries; thus a "good and clean" frequency setup does not work everywhere.

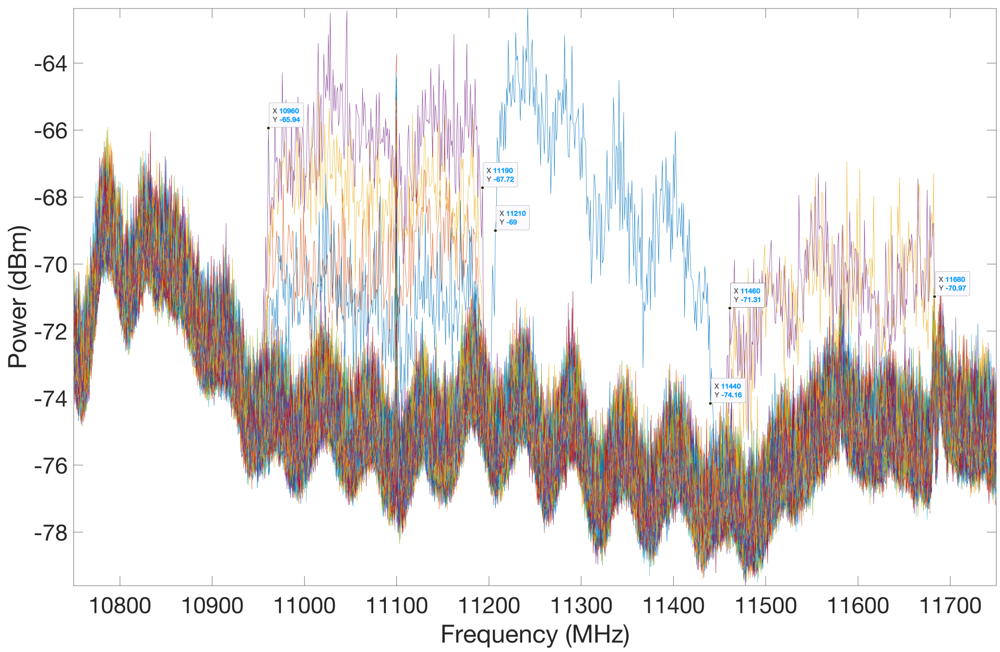

Fig. 3 OneWeb satellite interference monitored by MRO's 1.7-m solar telescope (10.7–11.7 GHz). When a OneWeb satellite passes the telescope's beam, the signal level rises by more than 10 dB.

5 Conclusions

As we have shown, frequency management and interference issues are especially challenging in VGOS operations. There are still some major open questions, especially a final VGOS frequency setup. This would facilitate further concrete actions in spectrum management. As long as the VGOS community has not decided on "its" frequency sequence, spectrum managers cannot request protection for the sequence from their national authorities. Likewise, VGOS radio astronomy is a passive service and must operate without interfering with other services. This weak position shall be altered by raising awareness (registration, ITU Report on Geodetic VLBI), agreeing on a VGOS frequency sequence in the near future, and searching for footnote protection in the radio regulations. In this regard, a close and fluent dialogue with national frequency administration is helpful. Each observatory should have a person responsible for spectrum management that could also be the link to one of the three regional spectrum management groups for radio astronomy such as CRAF (Europe/Africa), CORF (America), or RAFCAP (Asia-Pacific).

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