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Jamming Assessment and Identification (JASI) service ramp-up

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Abstract

Based on the fact that the number of radio-frequency interferences (RFI) – loss of telemetry at ground station level caused by the simultaneous emission of two satellites - suffered by CNES satellites has been increasing over the last few years and that this trend will most certainly accelerate in the future, CNES has decided to create a new service tackling this subject. This service, named JASI for Jamming Assessment and Identification (in this use, "Jamming" and "Interference" are equivalent), was developed around 2 axes : the identification of the origin of an RFI and the prediction of future RFIs. The identification part enables the satellites operators to know which satellites caused the RFI they suffered, mainly for information purpose. It is also of great value to the service team on 2 aspects. Firstly, this information enables them to monitor the RFI current situation and its evolution over the years. Secondly, it can be used to establish the list of satellites to monitor for the second axe of the service: the RFI prediction. These predictions enable the satellite operators to know when external satellites may cause RFIs. With this information, they are able to put in place some protective measures such as the swapping of the passes with the RFI with other ones or the interruption of the data downloading during the (usually short) periods of the RFIs. In order to provide these predictions, several problems were tackled, such as the modelling of the radio-frequency problem by a geometrical approach, the constitution of the list of satellites to be take into account or the accuracy of the predictions. The analysis of the results shows that, on one side, **nearly all of the RFI which occurred were predicted**, but on the other side an important part of the predicted RFI didn't occur, mainly because of the lack of access to the actual emission times of the external satellites. This problem needs to be addressed in order to have a RFI prediction service with an acceptable accuracy level.

Keywords: radio-frequency interference, X-band, CNES OCC, JASI

Acronyms/Abbreviations

ASI	Italian Space Agency
CNES	Centre National d'Etudes Spatiales - French Space Agency
EIRP	Effective Isotropic Radiated Power
GEO	GEostationary Orbit
ITU	International Telecommunication Union
LEO	Low Earth Orbit
NOC	Network Operation Centre
OCC	Orbit Computation Centre
O/O	Owner/Operator
RF	Radio-Frequency
RFI	Radio-Frequency Interference
TLE	Two Lines Element
TM	TeleMetry

1. Introduction

Radio-frequency interferences (RFI), i.e. interferences at ground station level due to the simultaneous emission of two satellites leading to telemetry (TM) loss, is becoming more and more noticeable at CNES level, especially in X-band. This observation and the fact that CNES activities in the X-band will increase drastically over the next few years led to the creation of a new service provided by CNES Orbit Computation Centre (OCC) in collaboration with CNES Network Operation Centre (NOC). This JASI service, which became operational in 2022, is built around 2 main axes :

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- the identification of the satellite responsible for suffered RFI
- the forecast of future RFIs

After describing in a few words NOC and OCC, the article will focus on the 2 axes of this service, focusing at first on the technical part and then presenting the achieved results.

2. CNES OCC and NOC

2.1. CNES Network Operation Centre

CNES Network Operation Centre mission is to operate all CNES S- and X-band multi-mission ground stations. This network is currently composed of 5 ground stations, two of which are situated in the polar region : Inuvik and Kiruna. The three others are located near Toulouse (France), in South Africa and French Guyana. The results presented in this article are mainly based on RFIs which occurred on one of these ground stations.

2.2. CNES Orbit Computation Centre

OCC is an operational multi-mission flight dynamics centre, working as part of the CNES Network Operation Centre (NOC). Part of its activities, such as the computation of antenna pointings or the computation of the satellites visibilities over CNES ground stations (for passes scheduling), are required so that NOC activities run smoothly. OCC has also a sound experience in terms of orbit determination, being responsible for all of this activity during all CNES LEOPs.

Historically, OCC was in charge of RFI computation for CNES versus CNES S-band satellites. It was then the logical place to host the new JASI service.

3. RFI origin identification

3.1. Description of a search

The first part of the JASI service revolves around the identification of the origin of observed RFIs in S and X-band: this service offers the possibility to CNES control centres to request a jammer search for any unexplained TM loss, after having excluded all the other possible causes, such as problem with the satellite or the ground station.

In order to perform such a search, the satellite Owner/Operator (O/O) needs to provide to JASI the following information :

- The satellite whose TM was lost
- The ground station concerned by the TM loss
- The exact times of the beginning and the end of the TM loss. The precision of the times needs to be in the order of 1 second.

The principle of the search is simple : for all the satellites orbiting the Earth, the angle between them and the satellite which suffered the TM loss is computed over a period of time containing the TM loss. The minimum of this angle is then compared to a threshold : if the minimum of the angle is below the threshold, the satellite is considered as a “candidate”. The threshold is defined taking into account the frequency band and the antenna’s diameter, with sufficient margin to ensure that the satellite responsible for the RFI is found. A more in-depth explanation can be found in 4.1.

In order to compute these angles, JASI needs to have access to the orbits of all of these objects, which is possible thanks to the French Space Situation Awareness (SSA) centre, collocated with OCC in Toulouse. The orbits they provide can either be TLEs published on the Space-track web site or in-house orbit determination using European sensors.

When all the candidates have been identified (usually up to 5, rarely more than that), they are inspected manually in order to identify the origin of the RFI. This inspection concentrates on finding the answers to the following questions :

- Does the satellite use the same frequency as the jammed one ?
- Is the satellite still active ?
- Does the satellite usually download data in the area of the jammed ground station ?

Some answers can be found on the internet, through specialized websites such as https://www.eoportal.org/satellite-missions. Some others could be found in some various databases such as the

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ITU one. However this latter in particular may not be accurate enough since the fillings tend to be conservative, in the sense that, for example, the declared frequencies can be much larger than the actual ones used in operations.

After reaching a conclusion on the origin of the RFI, all the work is logged in order to be accessible during searches for future requests.

3.2. RFI search example

To illustrate this process, here is the example of the RFI suffered by the satellite SWOT (https://swot.cnes.fr/en/SWOT/index.htm) on 2023/01/18 on Inuvik ground station. The observation was the following : during an X-band support over Inuvik (Canada) ground station on that day, 2 seconds of TM was lost. The diameter of the antenna is approximately 13m, leading to a -3 dB beam width of 0.2 degrees. In order to be positive that all the meaningful candidates are being identified, the search was done with a threshold of 1 degree. It began 10 seconds before the start of the RFI, and ended 10 seconds after, once again in order to be sure that all the meaningful candidates are being identified.

For this search, only 2 candidates were identified :

- A Molnyia satellite (Norad number : 10307) with an angle of 0.79 degree
- Landsat 9 (Norad number : 49260) with an angle of 0.11 degree

Given the low Norad number of the first candidate, the chances it's still active are slim at best. Furthermore Molnyia satellites don't have X-band capabilities. This candidate can be eliminated.

The second candidate is a NASA satellite, launched in Sept. 2021, whose mission is Earth Observation. Several sources such as https://www.usgs.gov/landsat-missions/usgs-landsat-ground-stations confirm that Landsat 9 uses X-band particularly over Fairbanks ground station, close to Inuvik. This answered the 3 questions : a live satellite using X-band in the vicinity of Inuvik. Furthermore, the date at which Landsat-9 and SWOT were the closest angularly from Inuvik match perfectly with the date of the RFI. Landsat-9 is then, with a high degree of certainty, the origin of the RFI suffered by SWOT.

The situation is illustrated on the map below (see Fig. 1) : both ground stations are plotted, Fairbanks (FCDAS) in Alaska and Inuvik (IVK) in Canada, the blue dot being SWOT and the yellow one being Landsat-9.

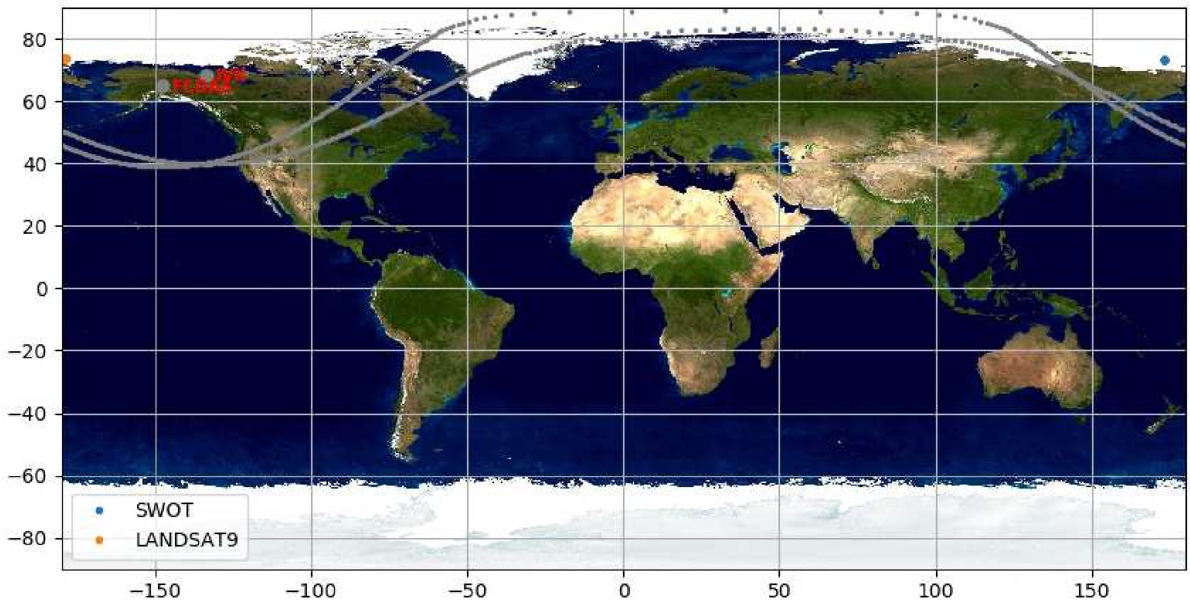

Fig. 1. RFI geographical situation

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3.3. RFI statistics

The first RFI searches for Low Earth Orbit (LEO) satellites done at OCC started approximately 10 years ago. At that time, OCC received only a few requests per year. A few years later, the results of these searches began to be stored punctually, until 2016 when it was done systematically. Thanks to this data, it is possible to have a global picture of the number of RFIs and its evolution over the years (see Fig. 2) at a CNES level.

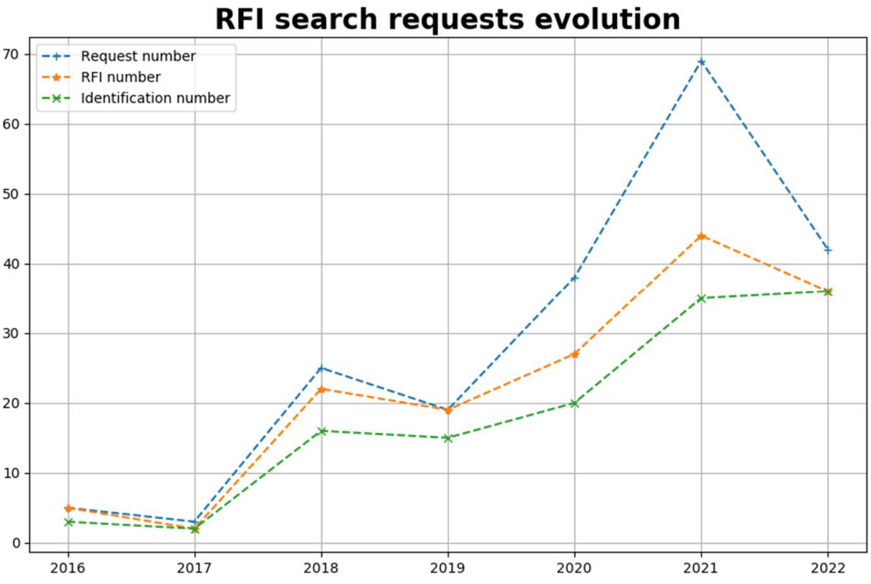

Fig. 2. RFI geographical situation

The blue plot represents the number of requests for RFI search received over the years. The orange one represents the number of events that were actually RFI. The difference between the 2 plots may be explained by ground station problems. The green plot represents the number of requests with a successful outcome.

The evolution of the requests number is in constant augmentation over the years. The first increase in 2018 is explained by the launch of first satellite using heavily the X-band over CNES network (particularly over Kiruna) followed by the second one by the end of 2020.

The requests concern mainly the X-band (90%) and the Kiruna ground station (85%). This is explained by the fact that :

- Most of the satellites using X-band use the totality of the band whereas each satellite uses a narrow part of the S-band.
- The CNES X-band passes use mostly Kiruna ground station. This will change in 2023 with the launch of SWOT.

The overall success rate is approximately of 70% with some noticeable disparities over the ground stations : **for example the success rate for Kiruna ground station reaches 92%**. Since JASI has access to the station logs for this particular ground station (contrary to some other ground stations), this difference can be explained by the fact that, it is possible to accurately determine if a request actually concerns an RFI instead of a ground station problem for this particular station as it can be the case for ground stations where the logs are unavailable.

Thanks to this high success rate, it is possible to know the main jammers of the CNES fleet. Overall, for the 120 RFI in X-band over Kiruna where the origin was identified, 63 single satellites were identified, meaning that in average one satellite caused 2 RFIs.

In 2022 most suffered RFIs were caused by Chinese satellites such as the GAOFEN family with 10 occurrences followed by some US commercial satellites (mainly Worldview and Skysat).

Overall, most suffered RFIs were caused by ESA satellites (mainly SENTINEL family and Cryosat) with 29 occurrences followed by Chinese satellites with 27 occurrences.

All the data can be found in Table 1 next page.

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Table 1. Identified jammers statistics

Families	Overall RFI numbers	2022 RFI numbers
China (GAOFEN, LT-1)	27	10
US commercial	14	6
Airbus	8	4
Russia (KANOPUS)	14	3
ESA	29	4
ASI	7	3
Other	21	8

The “Other” family is composed of various satellites, among which some are controlled by NASA, JAXA, CSA or the US Air Force for example.

As a conclusion, investigating every suspected RFIs allows to have a more precise picture of the current situation and its evolution over the years. **Even though, currently, only 0.5% of the X-band passes of CNES satellites over Kiruna (with approximately 7500 passes in 2022) suffer from RFI, it is CNES opinion that this number will starkly increase over the next few years**. In order to prevent too many TM losses or the loss of time-critical data, a second part of the service has been developed : the prediction of RFI occurrences.

4. RFI risk prediction

The second part of the JASI service consists in the prediction of RFI risks on a short-term horizon, usually 7 to 10 days in the future. The satellite O/O can be interested in two aspects of this service. The first aspect, which is the most intuitive one, consists in providing the O/O the prediction of the RFIs suffered by their own satellites. The reasons to use this service can be numerous. As an example, here are two of them :

- To prevent the loss of crucial data when the satellite doesn’t have the capability to download twice the same data.
- To ensure the download of time critical data: if the data is not downloaded swiftly after its collect, it becomes worthless.

The second aspect consists in providing the O/O the prediction of the RFIs suffered by external satellites and caused by the emission of their own satellites. Why would some O/O constraint their operations in order to protect the data of some external satellites ? Mostly because they have to coordinate with them. The main reasons for this type of coordination would be :

- These satellites belong in the same fleet, and there is some priority order among them. For example, at CNES level, the newer satellites will turn off their emissions if there is a risk they cause RFI to the older satellites.
- RF license agreement : a coordination can be put in place in order to obtain or keep an RF license over certain ground stations or as an agreement between 2 organizations, companies.

In the following paragraphs will be explained how RFI are modelled, the input needed to compute these RFI risks. It will be concluded by a critical analysis of the results provided by the service.

4.1. RFI modelling

In practice, an RFI occurs when the RF signal transmitted by an external satellite disturbs the budget link between one satellite and its ground station up to a point when it becomes so low that the ground station can’t decode the TM anymore. An RFI can be accurately modelled if at least the following data is known :

- Both satellites Effective Isotropic Radiated Power (EIRP)
- Signal over noise ratio leading to a link without error
- Radiation pattern of the on-board antennae of both satellites
- The actual attitude of both satellite
- The distance between the ground station and the satellites
- The TM modulation and the associated error correction code
- Frequency and bandwidth
- Etc …

Since these parameters can’t be known exhaustively for all the orbiting satellites, a simpler model needs to be used. **The chosen approximation to model RFI, used throughout the service, is purely geometrical** : an RFI

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occurs if the angle between the 2 satellites (with compatible emission frequencies) as seen from the ground station becomes lower than a threshold. On the contrary, it doesn't happen if this angle stays above this threshold. The rationale is the following : since the ground stations have directional antennae, when the angle between an external satellite and the tracked one is big enough, then the antenna can't receive the signal from the external satellite anymore. On the contrary, if it's small enough, then the antenna will receive signals from both satellites, leading to a possible RFI.

The threshold angle under which a RFI is mainly driven by the size of the antenna and the frequency band. A first approximation could be to use the -3 dB half-beam of the antenna. However, experience shows that this value is usually too small and twice this value would be better suited. For example, the service commonly uses a threshold of around 0.2 to 0.25 degrees for X-band antenna with a diameter of 11-13 m.

4.2. Difference between subscriber, external, jammed and jammer satellites

As explained, a RFI is defined by 2 satellites and a ground station where one of the 2 satellites downloads data to this ground station, part of this data being jammed by the emission of the other satellite. The satellite downloading data to the ground station is called the "jammed satellite". The satellite causing the RFI is the "jammer satellite".

When computing RFI predictions, the output is sent to the O/O of the satellite requesting the service. This satellite is called the "subscriber satellite". The other satellite is labelled "external satellite". If the O/O uses the service in order to protect its satellite from RFI, then the subscriber satellite is the jammed one in the predictions, the external satellite being the jammer one. On the contrary, if the O/O uses the service as part of a coordination with a goal to protect other satellites from the emission of its satellite, then the subscribed satellite is the jammer one, the external satellite being the jammed one.

What is important to keep in mind is that the subscriber satellite can be the jammed satellite when taking into account some external satellites and the jammer one when taking into account other external satellites. In other terms, the jammer or jammed status is linked to the loss of data, the subscriber or external status is linked to the reception of the predictions.

4.3. Definition of the external satellites

In order to compute the RFI prediction, the first thing to define is the list of the external satellites to be taken into account. To do that, the following questions need to be answered :

- which satellites may jam the subscriber satellites ?
- which satellites should be protected from the emissions of the subscriber satellite ?

The first question is the trickiest. One way to proceed could be to list all the satellites transmitting on frequency bands overlapping the ones used by the subscriber satellite. This list would then be filtered in order to keep only the satellites using ground stations in the same area as the ones of the subscriber satellite. Unfortunately these information are usually unavailable. Or erroneous. Or out of date… Depending on the need of the O/O, 2 different approaches can be used :

- Making a list of all the known jammers of a satellite using the same frequencies as the subscriber one. These jammers would have been identified by the first part of the service.
- Building the list incrementally, adding jammers after one or several RFIs have been caused by them.

A mix between these 2 approaches could be used : a core list is defined before launch, and then updated after RFI are observed.

The second question is more easily answered. The list of the satellites in front of which the subscriber satellite is turned off is linked to the existing coordinations.

4.4. Computation of RFI risk predictions

An RFI can happen if the following criteria are met :

- The angle between the 2 satellites as seen from the ground station of the jammed satellite is below a predefined threshold
- Both satellites are in visibility of the ground station of the jammed satellite
- The 2 satellites use the same frequency bands and the same polarization
- The jammer satellite is in emission

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- The jammed satellite is transmitting actual data (and not idle TM)

Based on these points, a list of input data can be defined, as presented in the paragraphs below.

4.4.1. Orbit prediction

Obviously, the main input which is needed is the orbit prediction of both satellites. For the subscriber satellite, the orbit should be delivered by the O/O in order to have the most accurate prediction. For the external satellite, different sources can be available, with an accuracy level differing greatly from one source to the next. O/O can be one of these sources if the external satellite is also a subscriber one (the best case scenario), or the French SSA if the satellite is tracked by French sensors. The TLEs are the source to be used when no other sources are available because of its lack of accuracy, when compared to the other ones.

4.4.2. Orbit uncertainty modelling

In order to take into account the differences in terms of orbit prediction accuracy, a basic modelling of the orbit uncertainty is used. The process which is explained below is also illustrated by Fig. 3.

The first step consists in assessing the along-track uncertainty of the orbit at the end of the computation period. This assessment uses a statistical approach which won't be described here. This along-track uncertainty is represented by the red parts of the orbits below. Statistically, the satellite can be at any of these positions. When computing the separation angle between the two satellites, instead of using the predicted positions (which leads to the one drawn in black), the positions used are the ones corrected by the orbit uncertainties in such a way that the separation angle is the smallest possible, as illustrated in red in the figure below.

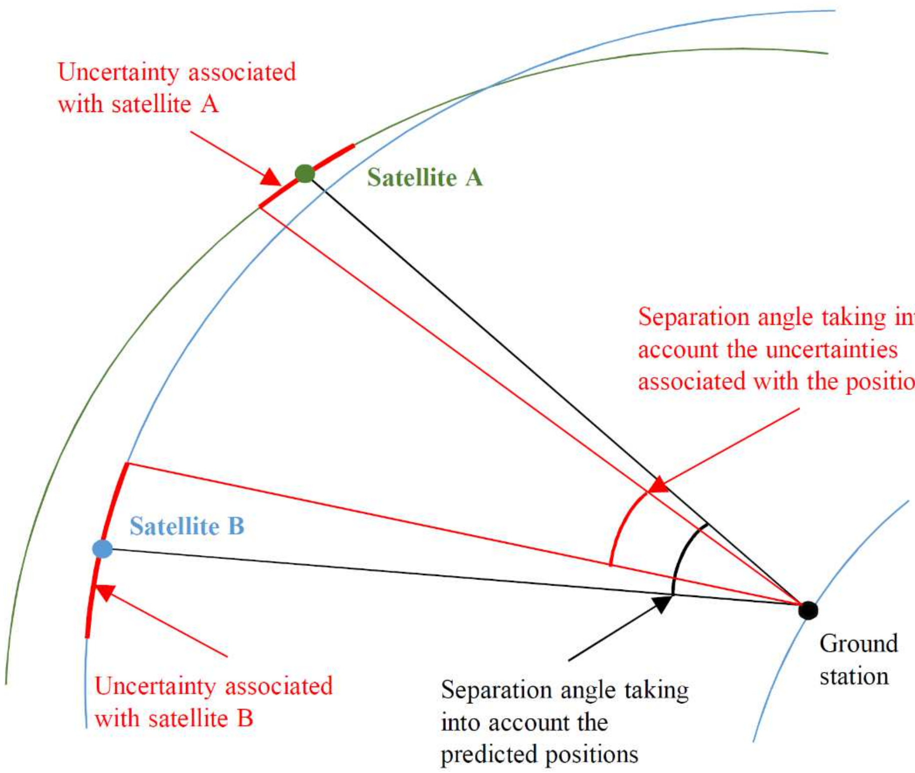

Fig. 3. Orbit uncertainty modelling

4.4.3. Antenna threshold

A threshold regarding the separation angle between the subscriber satellite and the external one is defined in order to identify an RFI : when the separation angle is inferior to this threshold, then an RFI can occur. As explained in paragraph 4.1, the threshold is linked to the antenna radiation pattern and to the accuracy of the antenna pointing. As an implication, a specific threshold should be defined for each antenna.

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As the threshold is a geometrical approximation of an RF phenomenon, it will be an imperfect representation of the reality. Its value can then be tuned depending on the safety level required by the subscriber : if the subscriber wished to be warned of every RFI, then the threshold value needs to be increased, with the risk of having more false RFI predictions. On the contrary, the threshold value can be set realistically in a way that most RFI will be identified, with the risk of overlooking some, leading to the punctual occurrences of RFI.

4.4.4. Emission modelling

As RFI can happen only if both satellites are emitting at the same time, it is important to model as precisely as possible their emission periods. In order to do that, the first step consists in listing the ground stations used by each satellites. For the subscriber satellite, this data is given at the subscription. For the external ones, it is usually based on assumptions, driven by experience, when the information is unavailable. Once the ground stations are identified, the second step consists in defining the emission strategy, i.e. the usual pattern used by a satellite when downloading data during a pass. Two different set of events are of interest:

- when is emission turned on and off ? During this period, the other satellite can be jammed (if it is downloading data)
- when is the data downloaded ? During this period, the satellite can lose data, meaning it can be jammed.

A simple way to define an emission strategy, used by default in the service, consists in assuming the satellite transmits over 0° elevation and downloads data over 5° elevation. Some other strategies could be :

- Permanent emission : even though it is against the ITU principles, some satellites still don't turn off their transmitters when not downloading data.
- Constant emission duration centered around the maximum elevation of the pass over a specific elevation. As an implication, if the duration over this elevation of a pass is inferior to this value, the pass wouldn't be booked so the satellite is assumed to stay off.
- Definition of a reference elevation over which data is downloaded with the start of the emission X seconds/minutes/degrees before reaching this elevation and the end X seconds/minutes/degrees after.

4.4.5. Pass booking status

JASI has access to the CNES scheduling office data so the predicted RFI can be filtered using the CNES subscriber pass status : if it is booked, then the prediction is sent to the control center. If it isn't the case, it is stored internally in case the pass status changes in the future. This type of filtering could be extended if JASI had access to information from other scheduling offices.

4.4.6. Computation process

The computation follows macroscopically the following steps :

- Computation of the geometrical visibilities of all the satellites from their own ground stations network (visibilities of the subscriber satellites and all the external ones associated with the subscriber)
- Computation of the emission periods of all the satellites, based on the visibilities (unless the satellite transmit permanently)
- For each emission period, computation of the separation angle between the subscriber satellite and the external ones as seen from the ground stations associated with the emission period
- When this separation angle is inferior to the threshold, then an RFI is identified and the accurate beginning and end times are computed
- Once all the RFI periods have been identified, they are filtered with the available booking status of the passes involved, when available
- The RFI are transmitted to the subscriber control centre

On the computation performance side, it takes 3 minutes to compute the RFI prediction for 35 external satellites, each transmitting over at least 3 ground stations. The maximal RFI duration that can be missed is 0.1 second.

4.5. Critical analysis of the results

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Since approximately 18 month, JASI has been computing X-band RFI risks for 10 of the CNES satellites and S-band RFI risks for 2 others. The S-band predictions and the X-band ones for 8 out the 10 are taken into account operationally. For the last 2 satellites, the results are stored internally and used to estimate the accuracy of the predictions.

The data analyzed below concerns the predictions computed for 2 satellites downloading data using X-band on Kiruna.

The accuracy can be determined by 2 factors :

- Were all the observed RFI predicted ?
- Did all the predicted RFI occur ?

Concerning the first question, as the O/O is using JASI each time their satellites suffer RFI, this question is easily answered. During 2022, these 2 satellites suffered in total 32 RFI. Over these 32 RFI, 15 concerned external satellites for which RFI predictions were computed. In the end only 2 of them were not predicted. Here are the reasons :

- The observed separation angle was 3 times over the threshold : 0.6° for a threshold of 0.2°.
- For the second RFI, the explanation is a bit more complicated. For these satellites, RFI are predicted for elevation over 5°. In this case, the minimal of the separation angle occurred between 4° and 5° of elevation, the separation angle becoming superior to the threshold before 5°. What happened is that the antenna tracked the external satellite instead of the subscriber one until it noticed the error, at which point it switched to program tracked. However, the switch didn't occur before 5° of elevation, leading to a TM loss.

Regarding the second question, the answer is less straightforward and more time consuming : for each RFI prediction, the antenna log was analyzed in order to try to understand which RFIs didn't happen.

In 2022, 238 RFI were predicted for these 2 satellites. **Over these 238 predictions, 209 didn't happened because at least one of the satellites didn't transmit.** The antenna logs contain data such as the signal level measured at the entry of RF chain as well as the signal over noise ratio which shows specific signature when the signal of an external satellite is received. In that case, the signature was absent from the logs, meaning the external satellite wasn't transmitting. In some cases, the subscriber satellites didn't transmit either (these satellites don't download data during the whole passes, making it difficult to predict accurately their emissions).

It leaves 29 predicted RFI during which both satellites (the subscriber and the external one) were actually transmitting and in the end 13 actual RFIs were observed, leaving 16 predictions for which the signal from the external satellite wasn't strong enough to cause a TM loss.

These statistics show it is imperative to share at least the booking status of the passes concerned by RFI prediction in order to have more accurate RFI prediction: if it were the case, the number of predicted RFIs which wouldn't occur would be divided by more than 5 !

These statistics also show that approximately half of the predicted RFIs don't occur even though both involved satellites transmit. This is mostly a limitation of the geometrical approximation of an RFI. It could be partially mitigated using a tuned antenna threshold specific to each external satellite based on the minimal separation angle of suffered RFIs.

5. Conclusion

CNES has started a service, named JASI, to handle RFI on 2 parts : identifying satellites responsible of suffered RFI and predicting future RFIs for subscriber satellites. On the first part, the service is fully operational with excellent results : more than 92% of identification success rate for RFIs occurring over station for which logs are accessible. The second part still needs tuning in order to provide accurate predictions, mostly concerning the knowledge of the actual emissions of external satellites. Without this information, at least 4 out of 5 RFI predictions won't occur because of the absence of emission of the external satellite. **This could be easily corrected by cooperating !**