NEW STM SERVICES: RADIO-FREQUENCY INTERFERENCE EVENTS DETECTION, CHARACTERISATION AND SOURCE IDENTIFICATION

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ABSTRACT

In the last decades, the number of man-made objects orbiting around the Earth has increased leading to an overcrowded Space Environment. This high number of objects poses a problem in the sustainability of current and future space activities. Over seven thousand active satellites make use of the radio electric spectrum for the reception of their telecommands, the broadcast of their telemetry signal and, in the case of telecommunication satellites, the transmission of their payload signals.

Typically STM activities have been focused on the assessment of collision risk. But this environment leads also to have radio frequency interferences that can cause the payload signal loss or unexpected blackouts of the satellite with the corresponding risk for its safe operation. These interferences can occur when in the vicinity of the signal path (satellite-earth) there is another satellite (above or below the emitting satellite) emitting another signal that causes an interference (intentionally or not) on the first one, overlapping in the same on-ground area. Also, an on-ground emitter can emit an interfering signal affecting the satellite signal.

New STM services are being proposed nowadays to mitigate the impact of these interference events allowing the spacecraft operator to plan their missions according to them. These services are focused in the prediction of new interference events, the identification of in-orbit emitting sources and the geolocation of on-ground emitters. This paper focuses on a possible design of STM services for radio-frequency interference detection and characterization.

1 SERVICES DESCRIPTION

The services proposed in this section aims to reduce the impact of Radio Frequency Interference (RFI hereafter) events on the satellites receiving these services. Not only the prediction of future events, but also the identification of possible in-orbit and on-ground sources would allow satellite operators to modify their operations plan according to these events, as well as to consider any mitigation action if required (e.g. frequency or polarisation switch, if possible).

Three different topics are tackled in this section. The first one is focused on the prediction and characterisation of future RFI events based on known satellites and on-ground emitters. The proposed methodology for this prediction strongly relies on the creation and maintenance of a database of known RF emitters, containing information about the carrier satellite or the ground station, the frequency of emission and signal polarisation.

The second topic is the source identification of in-orbit or on-ground emitters based on historical RFI events. The proposed methodology consists in correlating a list of RFI events suffered by a satellite with the history of RFI past events. First, it is tried to find events that perfectly match, in terms of dates and signal characteristics with those generated by unknown sources. If no source is identified, the software tries to identify some kind of pattern in the list of events that could match with any in-orbit or on-ground emitter. If the pattern fits with an on-ground emitter, the third step of the service is then triggered to narrow the on-ground location. Once the potential source is identified, the user can be notified of expected future RFI events to take the adequate mitigation action. Or even to decide a change in the signal properties or to coordinate mitigation actions with the other satellite owner, if possible.

Finally, the third topic is related to the geolocation of ground-based emitters causing RFI events. The proposed methodology is based on a passive-ranging method. Once the signal causing the interference is identified, a coordinated campaign with a second satellite irradiated also by the emitter causing the interference is required. By comparing the time and frequency difference of arrival of the signal between the two receivers and the orbit of both carrier satellites, it is possible to estimate the likelihood area where the ground-based emitter is located.

These three services have different processes that are common to all of them, such as the build-up and maintenance of very similar databases: orbital information, RF emitters' information and historical RFI events. Therefore, it is proposed to have all of them deployed and provided together.

1.1 Radio Frequency Interference prediction

The prediction and characterization of radio frequency interference events is very useful in the daily operations of a spacecraft, allowing the operator to know when the different signals of its satellite will be interfered and how much time this event will last so as to take the mitigation actions to avoid this problem in the future. The service proposed mainly consists in identifying all the possible RFI events during a forecasting period. It is worth to mention that any mitigation action is responsibility of the operator and is not part of this service.

To predict the RFI events, a catalogue of active satellites and information about their broadcasting instruments is required, especially frequency of emission, polarization, and bandwidth in which they operate their systems, and the pointing direction of these instruments to estimate the broadcast area projection.

In the GEO regime, the RFI is typically caused by other satellites in the close vicinity (usually carrying out proximity operations for eavesdropping or electronic jamming) or by near GEO orbits (satellites in re-location in the GEO ring) or even LEO/MEO satellites going through the GEO satellite beam. The typical duration of these interferences is expected to be short, due to the large difference in angular velocity between the two emitters.

The prediction of RFI events is based on a geometrical analysis considering that this is generated when there is overlap between the on-ground signal patterns of two satellites and the signal characteristics are compatible to interfere between them. This service will consider that one satellite can have several emitters or one emitter with several working configurations. Considering this, the filter of apogee-perigee typically used in the Collision Avoidance services is not valid since satellites orbiting in largely different regimes can have an overlap of their on-ground signal patterns. In this case, a different filter based on the angular distance between objects is proposed.

This service is aimed to be executed on a daily basis considering the most updated orbital and emitters' information. This data is stored in two databases that are required to be routinely updated as part of the service. These are:

- Orbital Catalogue: Containing the orbital information of all the objects considered for the analysis.
- RF Emitters database: Containing all the emitters' information, especially frequency and polarisation.

The users of the service contribute to these databases through the routine delivery of precise operator ephemeris and the emitting configurations on-board of their satellites. Autonomous catalogues like the one maintained by the EUSST Partnership or the Special Perturbation Catalogue (commonly known as SP Catalogue) published by the 18th Space Defence Squadron are also proposed to be used for the Orbital Catalogue.

There are several organizations that are in charge of regulating the usage of the radio electric spectrum. Some of these organizations are:

- Federal Communications Commission (FCC) dependent of the US Government.
- National Telecommunications and Information Administration (NTIA) dependent of the US Department of Commerce.
- The International Telecommunication Union (ITU) as the United Nations specialized agency.

The information gathered by these organizations can be employed together with that provided by the service users to contribute to the RF Emitters database.

In general terms, the RFI daily analysis is performed in an "All vs All" and "One vs All" modes. Besides, different execution times and scenarios (groups of satellites) can be considered in case that users provide the orbit information of their assets at different times.

On-demand analyses are proposed as part of the service, being triggered by user requests when a change in the orbit information is intended, such as non-planned manoeuvres or changes in the emitter's characteristics. This service can be used by the users to support their daily operations or for mission planning purposes. In some cases these non-planned manoeuvres or the emitters' modification could finally not be implemented if the RFI analysis gives unexpected or non-desired results. Therefore, this on-demand analysis does not affect the nominal RF Emitters database nor the nominal Orbital Catalogue, but it triggers an additional processing chain dedicated for this purpose.

According to the RFI event definition given in a paragraph above, the main information obtained as output of this prediction service consists in:

- Satellite ID object of interference
- Start time of the RFI event
- End time of the RFI event
- Satellite ID causing the interference
- Signal frequency of the RFI event

This information can be provided to the user in an automatic manner through an interface following a standardized format. Besides, this data can be complemented with graphical content such as timeline plots of the events. Additionally, an email communication is also considered, especially for the on-demand analysis due to the possible timeliness limitations.

All the RFI events predicted in the forecasting time period are stored in a database, the RFI Events Database, containing the full historical of events. This database is used for the following services to identify unknown sources.

1.2 Radio Frequency Interference source identification

The source identification service can be seen as complementary of the prediction one since both processing chains are quite similar with several processes in common. The main difference with the prediction service is that in this case, the purpose is not to predict future events but to identify the source based on the historical RFI events. It should be noticed that there are other possible sources related to space weather or atmospheric conditions, or even caused by obstructions of other objects like airplanes.

This service is triggered each time a user of the service notifies a list of RFI events suffered by any of its satellites that have been caused by unknown sources.

The identification of possible RFI sources is based on the correlation of the historical of RFI events provided by the service user and those stored in the RFI Events Database. If any unknown RFI event coincide in time with any of those on the database and the emitters' characteristics are compatible, the secondary satellite will be considered as possible candidate of the interference.

At this point, it is clear that the identification service has synergies with the prediction service as the correlation process requires to have a historical database of RFI events periodically updated. Besides, this service also requires to have two up-to-date databases containing the orbital information of in-orbit emitters and the emitters' information itself.

In a similar manner to the prediction service, the output obtained in this service contains the following information:

- Satellite ID object of interference
- Earth region where the interference is located (interval of longitudes and latitudes)
- Start time of the RFI event
- End time of the RFI event
- List of satellite ID candidates causing the interference

The list of possible candidates includes a score increasing with likelihood for each one being the source of the interference.

This information would be shared in an automatic manner with the user through an interface, including an email notification. It can be used by the service users to prevent any future RFI event, to take any mitigation action or just to establish a coordination with the RFI source operator. Moreover, if the source is found to be an on-ground emitter, the geolocation service can be triggered, as described next.

1.3 Radio Frequency Interference geolocation

Whereas both services previously detailed are focused on in-orbit RFI events, this service aims to locate on-ground emitters that are source of these kind of interferences.

The geolocation process is based on one of the most widely used techniques that uses the computation of the time difference of arrival (DTO or TDoA) or the frequency difference of arrival (DFO or FDoA), although several different techniques are available for the geolocation, as in [1] and [3]. For this purpose, it is required the collaboration of a secondary satellite being irradiated by the same interfering signal at the same time.

The service itself consists in identifying a neighbouring (secondary) satellite to the affected (primary) one. The secondary satellite needs to be configured, after contacting with its corresponding operator, to receive two different signals. The first one is the interfered signal affected by the on-ground station at an unknown location. The second signal, which comes from a known reference station, is considered as reference to have a common precise time. If available, GPS signal can be used for this purpose. Receiving both signals, emitted by both satellites, the TDoA and the FDoA can be computed by correlating the signal chunks. The characteristic site after the intersection of the obtained TDoA and FDoA solutions will represent a probabilistic location area of the interfering on-ground emitter.

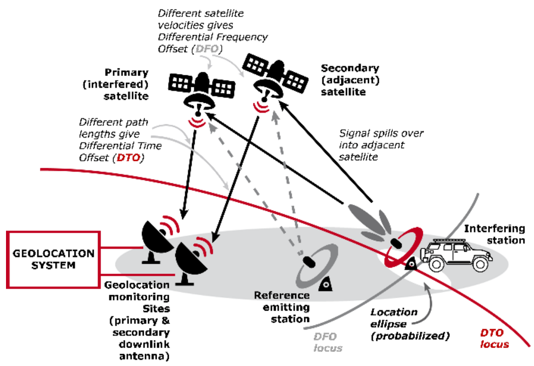

Figure 1. RFI geolocation scenario

Fig. 1 represents the scenario of the RFI geolocation service where it can be appreciated that the result obtained is a set of possible locations where the on-ground emitter could likely be placed.

For satellites in GEO, as shown in Fig. 2, the TDoA and FDoA solutions are usually perpendicular (roughly along a parallel and a meridian). The size of the probability area for the localisation of the RFI source mainly depend on the uncertainties of the TDoA and the FDoA solutions, and on the accuracy of the primary and secondary satellite ephemeris (see Fig. 3). Therefore, having a precise orbital catalogue, with continuously updated ephemeris for the GEO active satellites is key to provide a reliable and accurate service.

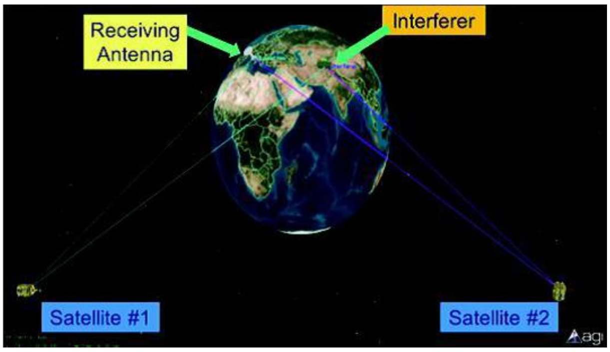

Figure 2. RFI geolocation geometry [2]

The description of the presented geolocation service focuses on satellites in GEO orbit, but the service could also be extended to satellites in other orbital regimes (e.g. MEO or LEO). Even though satellites in lower orbits have larger relative velocities and the RFI events are much shorter, they can suffer repeated RFI events above the areas with a RFI source. On the other hand, it is less likely to find a collaborative satellite receiving the same interference signal at the same time as the primary satellite.

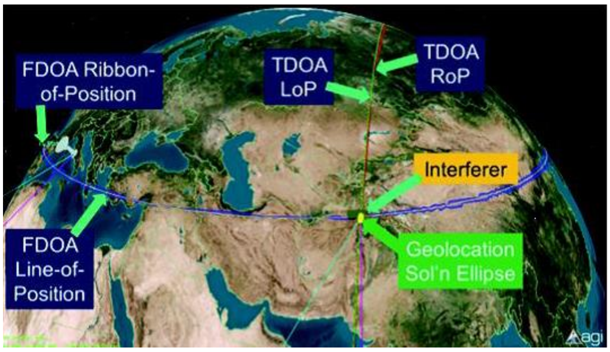

Figure 3. RFI geolocation error [2]

The proper execution of this service relies on the building-up and maintenance of three different databases or catalogues.

The Orbit catalogue contains the updated orbital information. This information will be provided by users, but also autonomous and external catalogues can be used as source for it.

The RFI events database contains the historical set of all RFI events detected and also information on the affected GEO satellites and the secondary satellites used for the geolocation process. In the proposed scenario, the storage of the signal samples used in the correlation process is not foreseen beyond the time strictly needed for the geolocation process.

The Geolocation database stores two types of information:

- *Satellite RF characteristics*. The satellite RF characteristics are needed to identify the optimum geolocation solution set and, ultimately, identify the most suitable secondary satellite. This information will be provided by users and satellite data providers.
- *Ground based RF emitters*. Maintaining an updated list of RF emitters, together with its characteristics and Carrier IDs (CID hereafter) is essential to identify the RFI source. The RF emitters shall also contain the contact information, to facilitate addressing the RFI event. This information will be provided by the users and satellite data providers, but also by additional stakeholders providing information on the characteristics of their facilities or public databases.

The service activation is done upon the notification of a list of RFI events or a continuous interference from the user that have been identified as originated by an on-ground emitter. The user will provide detailed information on orbital information and RF emission characteristics of the affected satellite. Based on the provided information, the service provider will be able to provide a preliminary list of possible interferers, based on the historicy of previous events and the nature of the RFI signal. In some cases, the RFI event will contain the CID of the interfering source. In these situations, the RFI source contact information will be provided to the user, based on the information stored in the geolocation database.

In order to provide the most complete RFI geolocation service, it would be advisable to verify if this event could have been caused by another satellite by correlating the events with the historical RFI database. If this is not the case, then it can be assumed that the RFI event has been caused by an on-ground emitter and the geolocation process will be triggered. Considering a scenario where only the geolocation service is available, any RFI event suffered by the service user will be considered caused by an on-ground emitter. In case the interference is not caused by an on-ground emitter, most likely the secondary satellite would not receive the same signal.

The geolocation service is in charge of selecting the most suitable adjacent satellites and reference carriers pairing with the primary satellite to be used for the geolocation. This identification will be automatically performed based on geometrical conditions (using the orbital information available in the orbit catalogue) and RF characteristics (frequency, polarization and polarization) which is stored in the geolocation database.

The selected secondary satellite operator will be contacted by the service provider to coordinate the usage of the corresponding satellite for the geolocation. The information exchanged with the satellite data provider shall contain all the required ephemerides to trigger the geolocation service and allow the acquisition of the proper RF samples.

As part of the geolocation service, the simultaneous signal chunks obtained by both satellites will be received and correlated by the service provider to derive the TDoA and FDoA measurements. For the correlation, it is necessary an accurate timing of the RF signal samples. The maximum accuracy in the correlation process is determined by the sampling of the signal and the timing accuracy of each sample. In some cases, the GPS time can be used as reference as most of the active satellites have a GPS receiver on-board. Also, as mentioned before, the GPS signal itself can be used as reference.

The result of the correlation will provide the TDoA and FDoA for each pair of signal samples. The TDoA provides a measurement on the difference between the reception times at both satellites. This quantity can be transformed into the pseudo-range from both satellites with respect the on-ground emitter. Combining the TDoA with the known satellite positions (through the precise ephemeris provided by the operators), the absolute distance between the satellites and the RFI source can be obtained. The other measured magnitude, the FDoA, will provide a determination on the relative velocity of the satellites with respect to the on-ground emitter. The combination of the measured relative velocity and the known velocity of the satellites will provide another set of possible locations on Earth.

The location of the RFI source can be further constrained by making use of the geolocation database. The maintenance of an updated geolocation database is crucial for the provision of the service. By identifying the list of possible RFI emitters within the probabilistic location area gives the final RFI source. In some cases, the contact information of the RFI source could also be contained in the geolocation database. In those cases where the CID is not provided in the RFI signal, several geolocation solution sets will be generated.

This information would be provided to the user through an automatic interface allowing the operator to contact the RFI source without further delay. This allows the satellite operator together with the RFI source operator. Apart from this, the set of possible locations is stored in the geolocation database together with the full historical solutions.

2 PROOF OF CONCEPTS

During the design of these new services, a set of simplified algorithms to carry out simulations and studies to test and validate the feasibility of the proposed approach has been carried out. So far, only the prediction of RFI events and in-orbit emitters' identification have been studied. Two general cases have been considered for this purpose that aim to cover the most common scenarios that can take place in the daily operations of LEO spacecraft.

The first case consists in the RFI events generated between a GEO and a LEO satellite, which is likely to cross the signal path of the GEO object several times per day. Considering that most of GEO satellites are for telecommunications, they are continuously emitting signal and this RF signal can interfere in the LEO spacecraft telemetry, the telecommand signals or even in the payload signal if the LEO satellite is intended for telecommunications.

Table 1. Case 1 details

Primary satellite	Satellite A (LEO)
Secondary satellite	Satellite B (GEO)
Start time	2022/09/01 00:00:00
End time	2022/10/01 00:00:00

The second case, and probably the most usual one when the service is active, is the RFI events between different LEO spacecraft. In this scenario, one LEO satellite and a set of active spacecrafts from a low-LEO mega constellation have been chosen. A smaller time interval has been simulated given the high number of satellites considered.

Table 2. Case 2 details

Primary satellite	Satellite A (LEO)
Secondary satellites	475 low-LEO mega constellation s/c
Start time	2022/09/01 00:00:00
End time	2022/09/15 00:00:00

For both cases, the simulation steps are similar. First of all, an analysis of the possible RFI events in the time period has been conducted. The second part of the proof of concept consists in correlating a list of unknown RFI events during a reduced time period with the candidate source satellite emitters. This will prove the service is able to distinguish from a catalogue of objects, those satellites that carry the most likely emitters that are causing a series of RFI events.

2.1 METHODOLOGY

The methodology used for these simulations does not consider the overlap of the on-ground signal paths because it assumes the simplification that every time a satellite passes through the satellite emitting cone with collinearity between them results in a RFI event. This leads to reduce the number of events and their duration since the overlap of the on-ground signal paths is longer than the pass through the signal cone. The software tool used for the computation of this kind of events is based on the following hypothesis:

- Collinearity between satellites. This is the period in which a pair of satellites have direct line of sight between them without the interference of the Earth.
- Signal cone penetration. This is the period of time in which a given satellite penetrates in the emission cone of another satellite.

The cone penetration event does not take into account the possible Earth interference and this is why both kind of events have to be simultaneously considered. Tab. 3 contains the configuration of the emitting cones used for these simulation scenarios. If the overlap of the on-ground signal patterns is considered, the duration of the events is expected to be longer but the time interval between two consecutive interferences, is similar.

The correlation process consists in determining which secondary satellite or satellites are causing the interference event given as input the historic of RFI events a satellite has experienced. If the RFI event matches in time interval with any of those listed in the historical database, the secondary satellite is considered as a possible source, increasing its score.

Table 3. Configuration of signal cones

Satellite	Cone pointing direction	Max. co-elevation
Satellite A (LEO)	Nadir	1 deg
Satellite B (GEO)	Nadir	40 deg
Low-LEO mega constellation s/c	Nadir	40 deg

It should be mentioned that at this point no information about the characteristics of the signal like frequency, polarisation or bandwidth are considered for this first prototype (it would simply imply a pre-filtering of the satellites to be considered in the case their emission characteristics are known). As part of the service, this information is required to dismiss those satellites emitting in different frequencies or those with broadcasting instruments that are not compatible with the RFI signal of the affected satellite.

2.2 Case 1: LEO vs GEO RFI events prediction

As mentioned before, this case of study considers the RFI events between a LEO and GEO satellites during a period of 1 month. The following table shows some details of the satellite orbits considered in this case.

Table 4. Case 1 satellites details

Satellite	Apogee [km]	Perigee [km]	Inclination [deg]
Satellite A (LEO)	697	695	98.18
Satellite B (GEO)	35803	35770	0.06

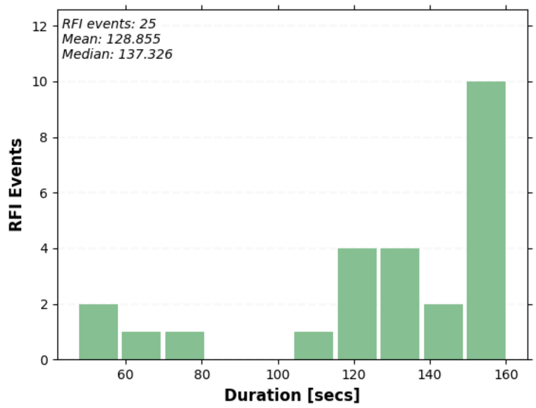

Figure 4. Case 1 RFI events duration

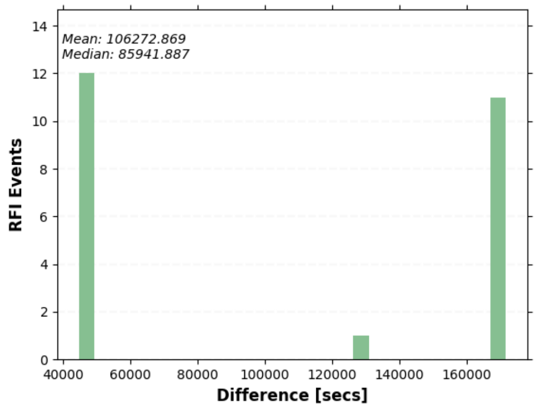

Figure 5. Case 1 RFI events interval

Fig. 4 shows the duration of the RFI events between these two satellites. This type of events have a duration of 2-3 mins according to the distribution of the duration. On the other hand, Fig. 5 shows the time interval between consecutive RFI events. There are two clearly differentiated frequencies between events, around 44000 secs (~12 hours) and 171000 secs (~48 hours). This can be observed by taking a look at Tab. 5 that shows the time interval of some of the RFI events of this case. The RFI events follow a kind of pattern: 12 hours between consecutive RFI events, then 48 hours and so on.

Table 5. Case 1 RFI events

RFI start time	RFI end time
9/1/22 07:50	9/1/22 07:53
9/1/22 20:11	9/1/22 20:13
9/3/22 19:54	9/3/22 19:57
9/4/22 08:15	9/4/22 08:17
9/6/22 07:58	9/6/22 08:01
9/8/22 07:43	9/8/22 07:44

2.3 Case 2: LEO vs LEO RFI events prediction

The purpose of this case of study is to reflect the problem in terms of RFI events for LEO satellites and mega-constellations. For this, a reduced set of 475 low-LEO spacecraft from a mega-constellation were considered.

Table 6. Case 2 satellite details

Satellite	Apogee [km]	Perigee [km]	Inclination [deg]
Satellite A (LEO)	697	695	98.18
475 low-LEO mega constellation s/c	~550	~550	~95

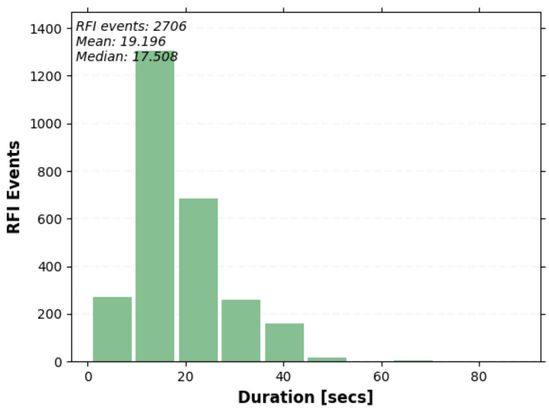

Figure 6. Case 2 RFI events duration

Fig. 6 shows that a total of 2706 RFI events are detected for the time period under analysis. Most of these have a duration of around 20 seconds that is much lower than those RFI events involving a GEO object due to the higher relative velocities between the satellites involved.

Fig. 7 shows the distribution of the difference between RFI events considering all the objects. It is clear that there are three main frequencies, the most important one around 2e05 secs (~55.5 hours = ~2.41 days).

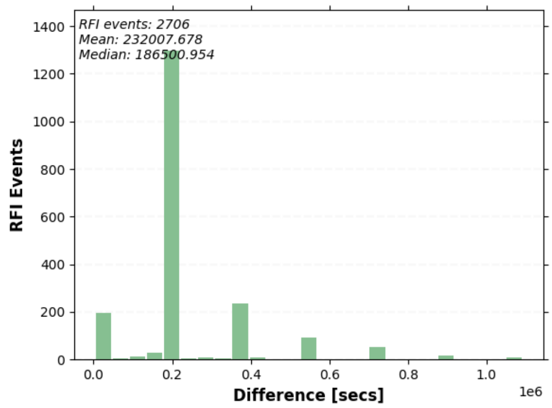

Figure 7. Case 2 RFI events interval

Fig. 8 shows the occurrences of RFI events per object, this is the number of times a single mega constellation satellite generates a RFI event. In the time period under analysis, the same spacecraft generates 10 RFI events at maximum. Most of these satellites generate between 1 and 5 RFI events.

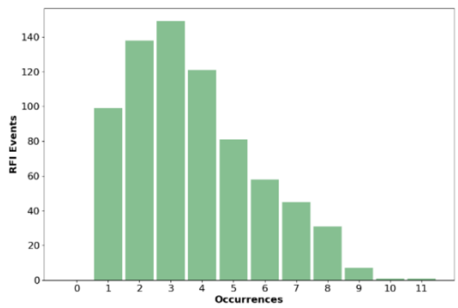

Figure 8. Case 2 RFI events occurrences for low-LEO s/c

2.4 Case 1: RFI source identification

For the correlation of RFI events with unknown secondary satellites, it is required to consider a list of historical past events. For this purpose, a database of RFI events has been simulated considering the LEO satellite as primary and four different GEO spacecraft as secondary, as reflected in Tab. 7.

A small set of three RFI events obtained in the Case 1 prediction have been considered. These events are introduced into the correlation software as they were caused from an unknown secondary source. The software shall be able to detect the Satellite B as the best possible candidate.

Table 7. GEO spacecraft considered for the RFI historical

Satellite Id	Longitude [deg]
Satellite B (GEO)	-30
Satellite C (GEO)	120
Satellite D (GEO)	-36
Satellite E (GEO)	-30

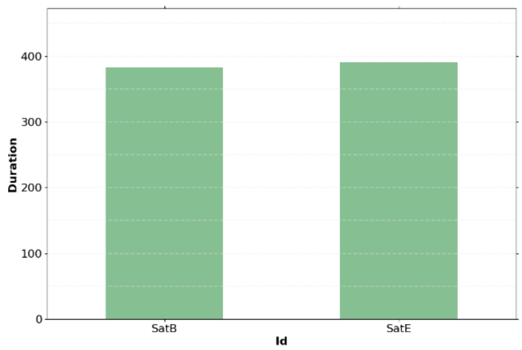

Figure 9. Case 1: occurrences of possible candidates

Fig. 9 shows the results of the correlation process in terms of occurrences, this is, the number of times the candidate has a RFI event in the historical at the same time as one of the RFI events given as input. In this case, two of the four possible candidates are candidates. This is straightforward since these two GEO satellites (Satellite B and E) are placed at the same longitude slot in the GEO orbit, as shown in Tab. 7.

The other two candidates are placed at different longitudes and the RFI events generated by these spacecrafts in the historical of events, do not match in time with the input list.

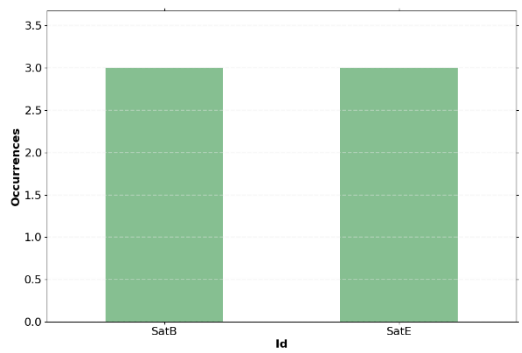

Figure 10. Case 1: duration of RFI events for candidates s/c

Apart from the occurrences, another parameter to determine the possible candidates is the duration of those RFI events. Fig. 10 shows the duration for the two possible candidates. Given that all of them are located at the same longitude, the duration is quite similar in all cases. As stated above, this is mainly due to the fact that these two satellites are placed within the same GEO slot.

The correlation of RFI events of a LEO object against candidates in the GEO regime could lead to mismatch those candidates since different GEO satellites located in the same longitude slot can generate simultaneous RFI events, if no signal characteristics are considered as constraints.

2.5 Case 2: RFI source identification

For the correlation process in this case of study, a small set of RFI events (48) are being correlated against the whole RFI catalogue (composed of 2706 RFI events for the 475 low-LEO satellites). The selected RFI events are those generated by the satellites showed in Tab. 8. As mentioned before, these RFI events are considered generated by an unknown secondary satellite.

Table 8. Set of low-LEO s/c RFI events to correlate

Satellite Name	Nb. RFI
Satellite F	9
Satellite G	9
Satellite H	9
Satellite I	10
Satellite J	11

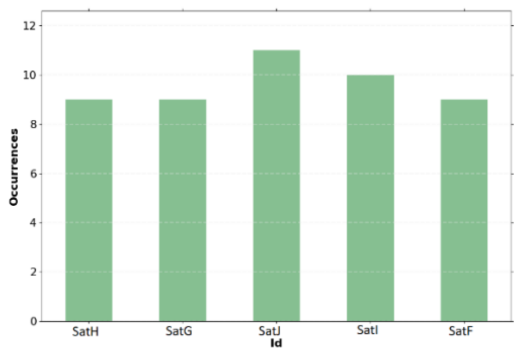

Figure 11. Case 2: occurrences of possible candidates

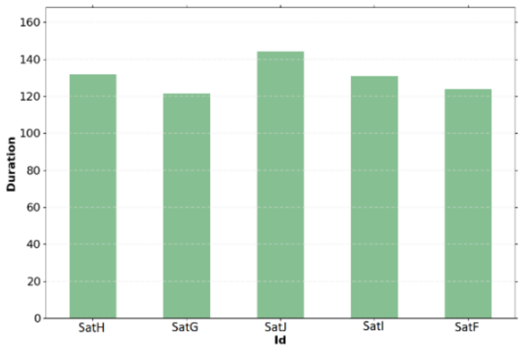

Figure 12. Case 2: duration of RFI events for candidates s/c

Fig. 11 shows the number of times each candidate has an RFI event in the historical list that matches any of the RFI events used as input. The results show the correlation tool is able to properly identify all the candidates. When only LEO satellites are considered in the correlation process, the identification of the candidates is more unambiguous and it does not lead to mismatch candidates.

Fig. 12 shows the duration of the RFI events matching the input list. Given that the number of RFI events for each candidate is similar, the total duration of all of them is also similar,

3 CONCLUSIONS

Considering a space environment with an increasing number of man-made objects orbiting the Earth, the problem of conjunction is not only reduced to the collision risk assessment. The use of the radio electric spectrum by all these satellites leads to having radio frequency interferences between spacecraft from different operators and orbital regimes, apart from possible interferences intentionally caused.

The aim of the services presented in this document is to mitigate the impact of any future interference by using the prediction service, and in case that a interference has occurred, to identify the in-orbit or on-ground source to cut-off the interference or to reduce its impact in future operations by contacting with the source operator.

These three services have a considerable amount of synergies since all of them require keeping up-to-date databases with orbital information and radio frequency emitters' information, in which the users of the services contribute with precise operator ephemeris and providing the information of their on-board emitting equipment.

In the case of the in-orbit identification service and in order to be as much reliable as possible, it requires having a historical database of past interference events to correlate the input list provided by the user. If this service is implemented together with the prediction one, this historical database would be readily available.

The proof of concept of the prediction service shows that the number of this kind of events considering a tiny set of satellites can be considerable. Interferences between GEO and LEO satellites have a larger duration in comparison to those between LEO spacecraft.

In the in-orbit source identification proof of concept, it is clear that when trying to differentiate between GEO satellites located within the same longitude slot, the identification can be wrongly done. In case this kind of data is available, it would be used to dismiss all those satellites with very different emitters' configuration in comparison with the affected satellite.

The provision of the services detailed in this document can play a key role in daily operations of spacecraft, in a similar way to the collision avoidance service. They can serve as analytical tool for operators to mitigate possible blackouts, prevent losses of signal and reduce the impact of these interferences in the satellites mission.

The design and studies of these services is still on-going, and it is foreseen to simulate more scenarios, including geolocation. However, the implementation of these new services seems feasible in the mid-term within the EUSST portfolio of services, which so far includes Collison assessment, fragmentation and re-entry analysis.

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