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Method on Estimation of RFI Sources for Stable Space Communication A Case Study of the NGEO KARI Program

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Abstract

The global space industry is rapidly transforming with the advent of the New Space era, predominantly driven by the private sector. In response to this trend, the Republic of Korea launched the KASA on May 27, 2024, marking the commencement of a new era in Korean space activities. The advancement of new operators in the space industry offers significant advantages in promoting the development of the country and the space industry and pioneering new fields. However, the use of limited resources such as frequencies and orbits are essential for space activities, and interference between existing and new operators in the use of these resources can result in setbacks, causing the nation to fall behind in the New Space era. We already understand the importance of managing these limited resources, as we are exposed to the risk of physical damage caused by orbital interference from numerous pieces of satellite debris currently located in space orbits. Frequencies are one of the most crucial limited resources for successful communication in space or earth observation missions. They are essential not only for satellite communication in general mission operations but also for monitoring and avoiding space objects, which is a critical security aspect. In the upcoming human spaceflight space era, these frequencies are directly linked to safety. Recently, RFI have increasingly caused failures in satellite missions during earth observation missions in the Republic of Korea. This study details the methods used to identify RFI sources, analyzing and estimating interference that occurred during the operation of the KARI non-geostationary satellite programs, such as the KOMPSAT and CAS500 series. This research utilizes two primary data sets: satellite TLE data and the ITU-R Satellite Network data. The estimation process begins with initial data processing, followed by simulations to identify RFI sources. Through these estimations, the study aims to secure frequency usage rights for each station and contribute to the establishment of a stable space communication environment.
Keywords: KOMPSAT, CAS500, RFI, ITU-R, Satellite Network

Nomenclature

$C_{downlink}$	Carrier power of downlink
$I_{downlink}$	Interference power of downlink
$P_{Sat\ Max}$	Transmitting satellite power
$P'_{Sat\ Max}$	Interfering transmitting satellite power
$G_{Rx\ ES\ Max}$	Receiving gain of the earth station
$G(\theta)_{Rx\ ES}$	Interfered earth station sidelobe gain in the direction of the interfering satellite
$G(\theta')_{Tx\ Sat}$	Transmitting satellite gain towards the receiving earth station
$G'(\Phi)_{Tx\ Sat}$	Interfering transmitting satellite antenna gain in the direction of the interfered earth station
E_b/N_0	Energy per bit to noise power spectral density ratio
PFD	Power Flux Density
$FSL_{downlink}$	Free Space Loss in the downlink
$FSL'_{downlink}$	Free Space Loss of the interfering transmitting satellite

Acronyms/Abbreviations

AOS	Acquisition of Signal
API	Advance Publication Information
CAS500	Compact Advanced Satellite 500
CR	Coordination Request
DBIU	Date of Bringing into Use
EESS	Earth Exploration Satellite Service

ES	Earth Station
GEO	Geostationary
IFIC	International Frequency Information Circular
ITU-R	International Telecommunication Union Radiocommunication sector
JGS	Jeju Ground Station
KARI	Korea Aerospace Research Institute
KASA	Korea AeroSpace Administration
KGS	KARI Ground Station
KOMPSAT	Korea Multi-purpose Satellite
LHCP	Left-handed Circular Polarization
MIFR	Master International Frequency Record
NGO	Non-geostationary
RFI	Radio Frequency Interference
RHCP	Right-handed Circular Polarization
RR	Radio Regulations
SATCAT	Satellite Catalog Number
SNS	Space Network Systems database
SSA	Space Situational Awareness
TLE	Two-Line Element
TT&C	Telemetry, Tracking, and Command
UN	United Nations
UTC	Universal Time Coordinated

1. Introduction

The International Telecommunication Union (ITU), established to standardize and regulate international telecommunications and radio frequency services, was designated as a specialized agency of the United Nations (UN) under Articles 57 and 63 of the UN Charter. The ITU Radiocommunication Sector (ITU-R) manages the implementation of the Radio Regulations (RR), an international treaty that radiocommunication services. This sector aims to ensure the efficient use of the radio-frequency spectrum, foster international cooperation, provide technical services, and promote the harmonized use of radio communication among UN member states.

UN member states assume the obligation to comply not only with the ITU Constitution and Convention but also with the RR, which serve as binding instruments. Article 103 of the UN Charter states that obligations under the Charter shall prevail in case of conflict with other international agreements, emphasizing the authority of norms established by UN specialized agencies. Consequently, the RR represent mandatory international standards rather than non-binding recommendations.

To ensure the efficient, rational, and economical use of limited outer space resources such as orbits and frequencies, ITU-R establishes the principle that national radio stations must not cause harmful interference to those of other countries. It also regulates priority in the use of these resources under the *'first-come, first-served'* principle through the satellite network filing process.

Accordingly, UN member states are under an international obligation to follow the RR and satellite filing procedures established by the ITU-R, thereby ensuring the peaceful and effective use of finite resources, preventing cross-border interference, and contributing to the stable development of the global telecommunications order.

On one hand, in the New Space era where private entities increasingly lead space industry development, many countries have raised concerns that national radio laws, other than the RR, may restrict private sector participation. To address this, the introduction of blanket licenses has been proposed to ease regulatory barriers and encourage commercial space activities.

While blanket licenses are important for promoting private engagement in space. However, without a clear understanding of how space resources are currently managed, such licensing could unintentionally undermine the operational frameworks established during the Old Space era.

This study examines the concept of satellite networks and the filing procedures defined by the ITU-R. The study also presents a method for identifying potential RFI sources using Satellite Network Data and Space Object Catalog Data, and analyses actual interference cases in the NGEO KARI Program, which operates under the Earth Exploration-Satellite Service (EESS). It is hoped that the findings of this study will help support the development of stable space communication in the New Space era.

2. International Satellite Network Registration under ITU-R

A satellite network refers to a system composed of a satellite and the associated earth station (ES) that communicates with it as shown in Fig. 1. The ITU-R manages these satellite networks to ensure the fair and efficient use of satellite frequency resources worldwide.

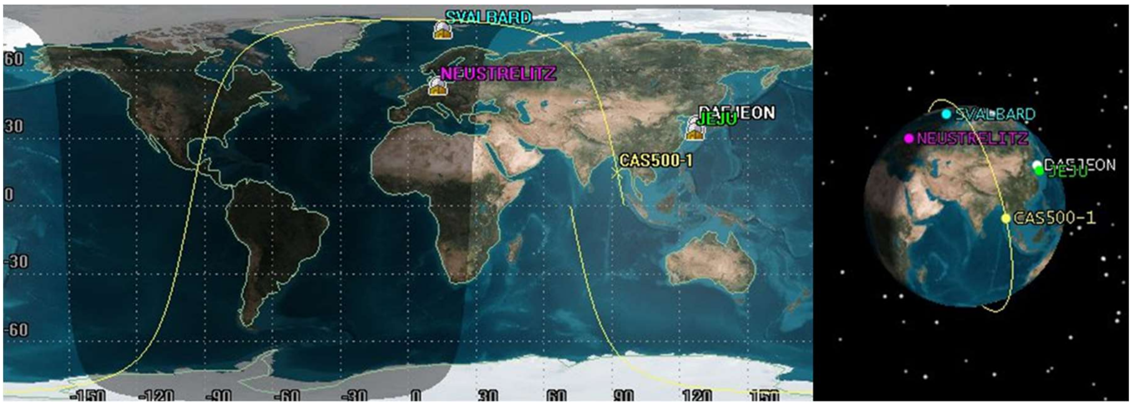

Fig. 1. Satellite and ES information in CAS500-1 Satellite Network

The *'first-come, first-served'* principle for the use of outer space resources grants international priority rights over frequencies and orbital positions through satellite network filings, as shown in Fig. 2.

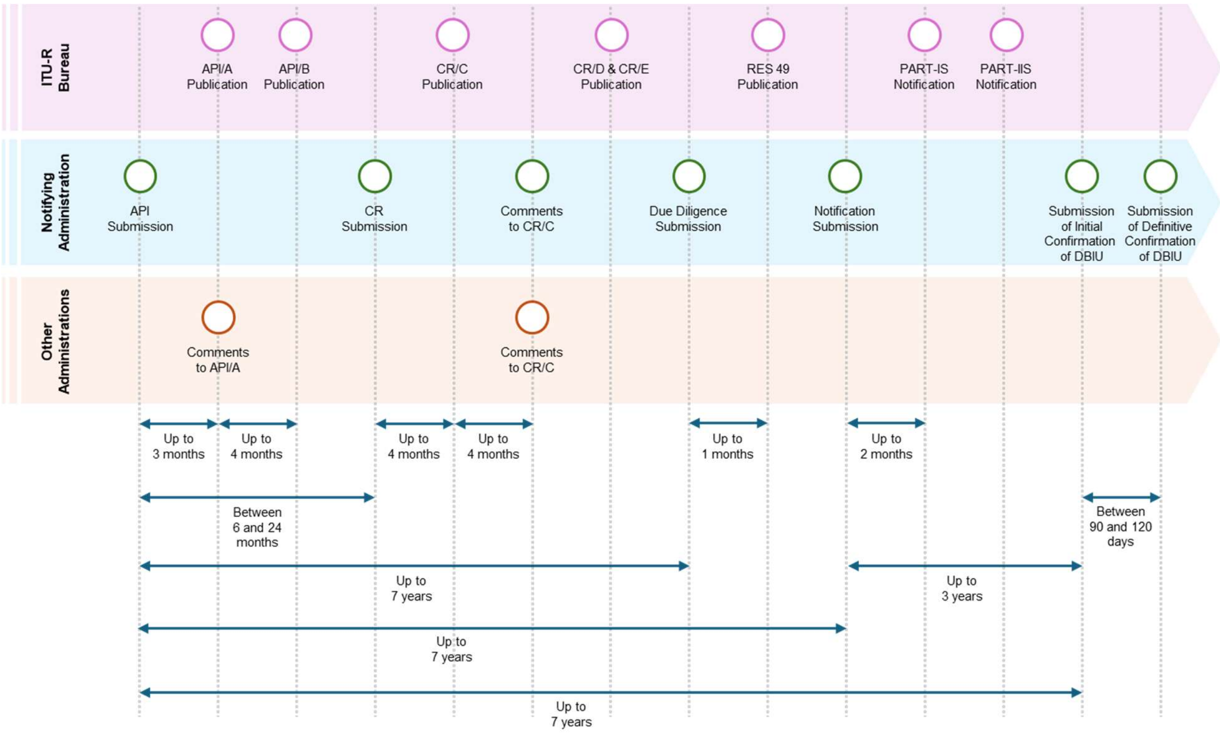

Fig. 2. Satellite Network Filing Procedures of the ITU-R

When two or more administrations intend to use similar frequency bands or orbital slots, the administration with priority must coordinate with the others to mitigate potential mutual interference and ensure harmonized frequency use. The coordination process generally follows the steps below. It should be noted that, depending on the function of the satellite system, some or all of these steps may be applicable.

- Advance Publication Information (API): In this initial stage, the new administration publicly announces its intent to use a satellite network. Administrations with pre-existing rights may request technical analysis regarding the proposed frequencies or orbits.

- Coordination Request (CR): This is the formal stage for coordination between satellite networks. Based on detailed specifications, the involved parties evaluate the potential for interference and perform coordination to ensure compliance with the RR, using ITU-R technical documentation to prevent harmful interference.

- Notification and Recording: This is the final stage for entry into the Master International Frequency Register (MIFR) following the completion of coordination. In this stage, the newly coordinated administration submits a notification through PART-IS. The Radiocommunication Bureau (BR), in accordance with the relevant provisions of the Radio Regulations (RR), then either proceeds to notify the registration in the MIFR through PART-IIS, or issues PART-IIIS to return the submission to the administration for revision or correction.

- Once the satellite network is successfully recorded in the MIFR, the new administration submits confirmation to the ITU-R that the network is operational. This final submission completes the full registration process and secures the administration's international rights to the satellite network.

Although the ITU-R satellite network filing process is highly efficient, it only applies at the international level, governing coordination between countries. Once a satellite system is successfully registered with ITU-R, it must then comply with the domestic laws and regulations of the country in which the system operates to obtain the necessary frequency authorization or license. At the domestic level, each country has its own regulatory framework for frequency allocation and licensing. In general, national radio raw the use of satellite frequencies in the following order:

- Priority of Operators
  - Tier 1: Operators who are nationals of the country (i.e., domestic operators)
  - Tier 2: Operators who are non-national (i.e., foreign operators)

- Priority of Services
  - Tier 1: Public and Military
  - Tier 2: Government and Civil
  - Tier 3: Commercial and Other

In addition, the ITU-R satellite network filing process functions as a form of international certification for satellite systems. A satellite system that does not complete the filing process or finalize coordination in accordance with the RR is considered non-compliant at the international level. As such, it is treated as an unauthorized space object, which may negatively affect the use of foreign launch vehicles or the use of radio frequencies in other countries.

3. Data for Estimating RFI Sources

For correct analysis of RFI sources, orbital information of the interfering source and detailed link characteristics related to its frequency. To obtain such parameters, one may refer to data such as the Space Frequency Coordination Group (SFCG) database, the UCS Satellite database, and commercial satellite data services as Seradata. However, the SFCG database is accessible only to member organizations, commercial services as Seradata incur additional costs, and publicly available databases suffer from long update cycles, limiting their usability for detailed analysis.

In this study, we estimate RFI sources using data that support the full lifecycle of satellite systems, specifically the ITU-R Satellite Network System database (SNS) and the Space-Track Catalog database, which includes Two-Line Element (TLE) data.

3.1 ITU-R SNS: Frequency Data

The ITU-R SNS provides not only orbital information and frequency parameters of satellites registered under satellite networks but also includes details about the associated ES as bodies, such as their geographic locations and assigned frequency parameters. As a result, the SNS serves as a critical resource for understanding how frequencies are being used in practice. However, the satellite network name in the ITU-R SNS does not always correspond to the actual satellite name, and it does not include real-time operational data such as Satellite Catalog Number (SATCAT), which are essential for tracking satellite positions. Moreover, satellites with different names serving the same mission may be registered under a single satellite network for more flexible management. As a result, one satellite network can include multiple satellites, such as satellite constellations or satellites sharing the same orbit, as well as multiple corresponding ES. Due to these limitations, the SNS alone is insufficient for analyzing interference sources that occur in real time.

3.2 Space-Track Catalog: Orbital Data

For Space Situational Awareness (SSA), the Space-Track Catalog database provides TLE sets that the orbits of all identifiable space objects. In addition to orbital data, the catalog database includes information such as the object name, SATCAT, launch site, launch date, country code, and operational status, making it a valuable resource for identifying potential interference sources in real time. However, since the catalog does not include radio parameters, such as the frequencies used by each space object, it is difficult to rely on it alone for comprehensive RFI analysis.

4. Method for Estimating RFI Sources

Satellite system operators do not have correct information about which satellite is an RFI source, which ES it is communicating with, or what frequency bands and beam parameters are being used. However, operators have precise information regarding their own satellite systems and ESs, including the detailed frequency parameters and geographic locations used by each station.

In this section, we present a method for estimating and analyzing candidate RFI sources from the perspective of a satellite system operator.

4.1 Events of RFI in the NGEO KARI Program

The Korea Aerospace Research Institute (KARI) operates the national satellite program, which includes the KOMPSAT and CAS500 series, to efficiently operate EESS missions. Satellite operations are conducted using the KGS in Daejeon and the JGS in Jeju Island, Republic of Korea. As shown in Table 1, the RFI event was confirmed in KOMPSAT-3 and CAS500-1. As shown in Fig. 3 and Fig. 4, it was confirmed that Eb/N_0 was degraded in each polarization due to RFI.

For the information, due to the mission characteristics of the NGEO KARI Program, cases where the Eb/N_0 degradation of both Right-handed Circular Polarization (RHCP) and Left-handed Circular Polarization (LHCP) simultaneously exceeds 50% on the y-axis are explicitly not considered RFI.

Table 1. RFI events in KOMPSAT-3 and CAS500-1 satellites

Date	Satellite Name	ES Name	RFI Start Time	Note
2024. 01. 03.	KOMPSAT-3	JGS	17:59:02	Fig. 3. (a)
2024. 03. 02.	KOMPSAT-3	JGS	05:21:01	Fig. 3. (b)
2024. 03. 20.	KOMPSAT-3	JGS	18:50:05	Fig. 3. (c)
2024. 05. 25.	CAS500-1	JGS	02:13:52	Fig. 4. (a)
2024. 06. 08.	CAS500-1	JGS	02:42:48	Fig. 4. (b)
2024. 06. 20.	CAS500-1	JGS	15:22:01	Fig. 4. (c)
2024. 06. 23.	CAS500-1	JGS	02:52:50	Fig. 4. (d)
2024. 07. 21.	CAS500-1	JGS	15:22:18	Fig. 4. (e)

4.2 Frequency Parameters for Estimating RFI Candidates

The frequency parameters used by KOMPSAT-3 and CAS500-1 are listed in Table 2. To estimate candidate RFI satellite networks, the ITU-R SNS was filtered for satellite networks worldwide that either match or partially overlap with these frequency parameters. Along with the relevant frequency data, the associated ES of these networks were also filtered.

Table 2. Frequency Information of KOMPSAT-3 and CAS500-1 in SNS

Satellite Networks Name	ITU Beam Name	Band	Link	Polarization	Frequency Min [MHz]	Frequency Max [MHz]
KOMPSAT-3	K3XD1	X	Downlink	LHCP/RHCP	8025.000	8345.000
	K3XD2	X	Downlink	LHCP/RHCP	8045.000	8365.000

	K3XD3	X	Downlink	LHCP/RHCP	8065.000	8385.000
CAS500-1	C1SDL	S	Downlink	RHCP	2265.465	2265.735
	C1SDN	S	Downlink	RHCP	2263.933	2267.267
	C1XD1	X	Downlink	LHCP/RHCP	8025.000	8345.000
	C1XD2	X	Downlink	LHCP/RHCP	8045.000	8365.000
	C1XD3	X	Downlink	LHCP/RHCP	8065.000	8385.000

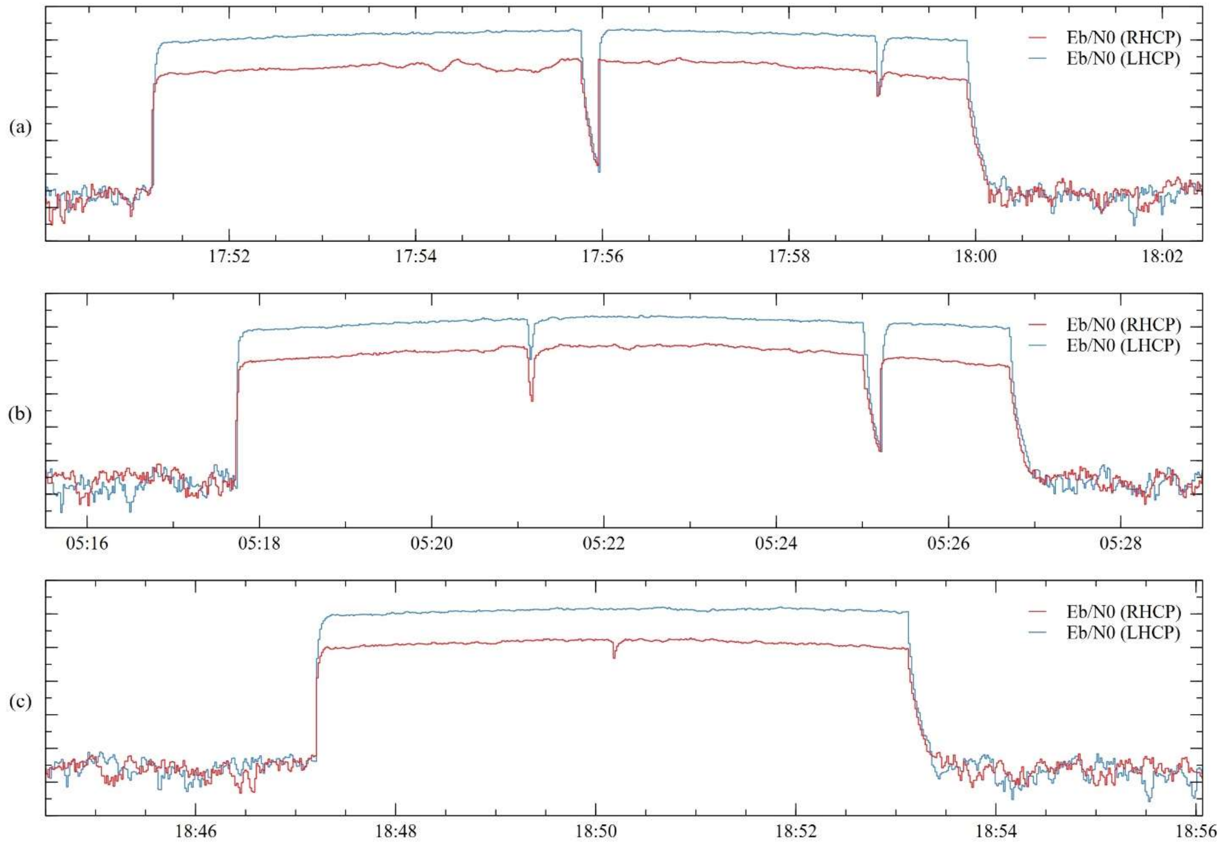

Fig. 3. E_b/N_0 degradation in KOMPSAT-3 X-band Downlink due to RFI

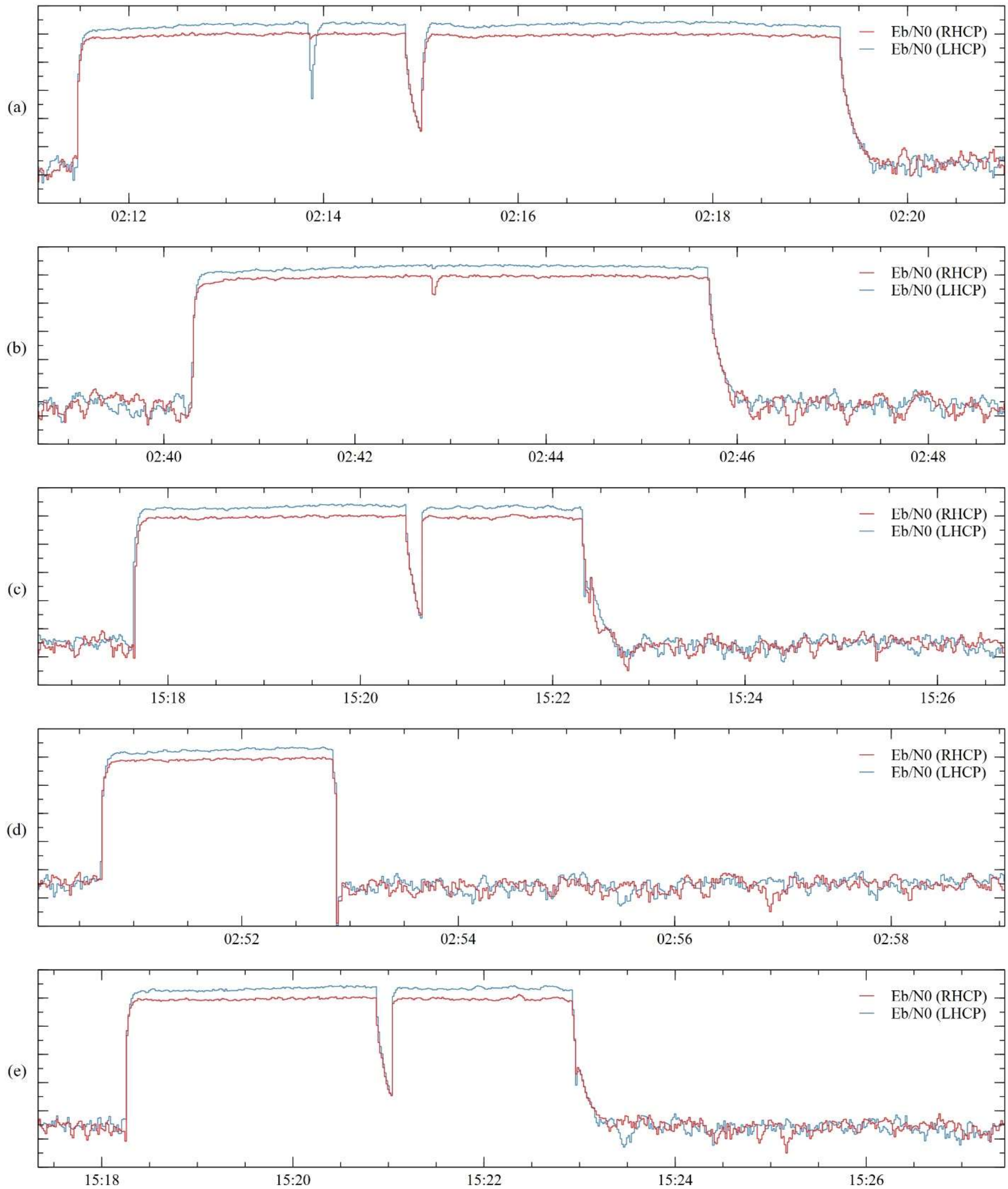

Fig. 4. E_b/N_0 degradation in CAS500-1 X-band Downlink due to RFI

4.3 Orbital Parameters for Estimating RFI Candidates

Using the Space-Track Catalog database, satellites operating worldwide on the dates when RFI was confirmed in KOMPSAT-3 and CAS500-1 were filtered. Subsequently, based on the specific times of the RFI events, satellites that were either adjacent to KOMPSAT-3 and CAS500-1 or within the beamwidth of the associated ES were estimated as candidate RFI sources.

4.4 Identification and Analysis of RFI Candidates through Estimation

The identified RFI sources were estimated by analyzing parameter similarities between the candidate RFI satellite networks obtained in Section 4.3 and the candidate RFI sources obtained in Section 4.4. Based on this estimation, the final RFI sources were estimated, and their corresponding ITU-R SNS information is presented in Table 3.

Table 3. Frequency Information of Identified RFI Sources in SNS

Date	ITU Beam Name	Band	Link	Polarization	Frequency Min [MHz]	Frequency Max [MHz]
2024. 01. 03.	CO2XD1	X	Downlink	LHCP/RHCP	8062.500	8362.500
	COXD1	X	Downlink	LHCP/RHCP	8062.500	8362.500
2024. 03. 02.	XD	X	Downlink	LHCP/RHCP	8035.000	8050.000
	XDD	X	Downlink	LHCP/RHCP	8025.000	8400.000
2024. 03. 20.	TTCDK	X	Downlink	LHCP/RHCP	8392.900	8399.100
	XDT	X	Downlink	LHCP/RHCP	8025.000	8400.000
2024. 05. 25.	B3	X	Downlink	LHCP	8025.000	8400.000
	B3	X	Downlink	LHCP	8040.500	8360.500
2024. 06. 08.	XDN	X	Downlink	LHCP/RHCP	8072.500	8177.500
	XDN	X	Downlink	LHCP/RHCP	8247.500	8352.500
2024. 06. 20.	SD	S	Downlink	RHCP	2235.000	2240.000
	SG	S	Downlink	RHCP	2230.000	2265.000
2024. 06. 23.	SD	S	Downlink	RHCP	2235.000	2240.000
	SG	S	Downlink	RHCP	2230.000	2265.000
2024. 07. 21.	SD	S	Downlink	RHCP	2235.000	2240.000
	SG	S	Downlink	RHCP	2230.000	2265.000

For the RFI analysis of the identified candidates through estimation, the Carrier-to-Noise ratio (C/N) was calculated for the X-band downlink of KOMPSAT-3 and CAS500-1. In cases where parameters of candidate RFI sources were not obtained, the analysis was conducted under a worst-case assumption by applying the same parameters used for KOMPSAT-3 and CAS500-1.

$$C_{downlink} - I_{downlink} = \begin{cases} if \ \geq 0 \ then, \ no \ RFI \\ if \ < 0 \ then, \ potential \ RFI \end{cases} \quad (1)$$

$$C_{downlink} = P_{sat\ Max} + G(\theta)_{Tx\ Sat} + G_{Rx\ ES\ Max} - FSL_{downlink} \quad (2)$$

$$I_{downlink} = P'_{sat\ Max} + G'(\Phi)_{Tx\ Sat} + G(\theta')_{Rx\ ES} - FSL'_{downlink} \quad (3)$$

5. Results

As a result of the RFI analysis performed on the identified candidates through estimation, it was confirmed that increases in PFD occurred at the same time as the degradation of E_b/N_0, as shown in Fig. 5 and 6. At those moments, the C/N was confirmed to be lower than 0, suggesting that the C from the RFI sources had an impact on the mission of the NGEO KARI Program.

A notable case occurred when the ES in the NGEO KARI Program performed Telemetry, Tracking, and Command (TT&C) operations using auto-tracking in the S-band. As shown in Fig. 6 (c), (d), and (e), the E_b/N_0 in the X-band downlink signal is none following a spike in PFD. This indicates that the ES, while attempting to auto-track the stronger S-band signal from the RFI source, whose C was higher than that of CAS500-1, lost lock on the planned X-band downlink, resulting in communication loss.

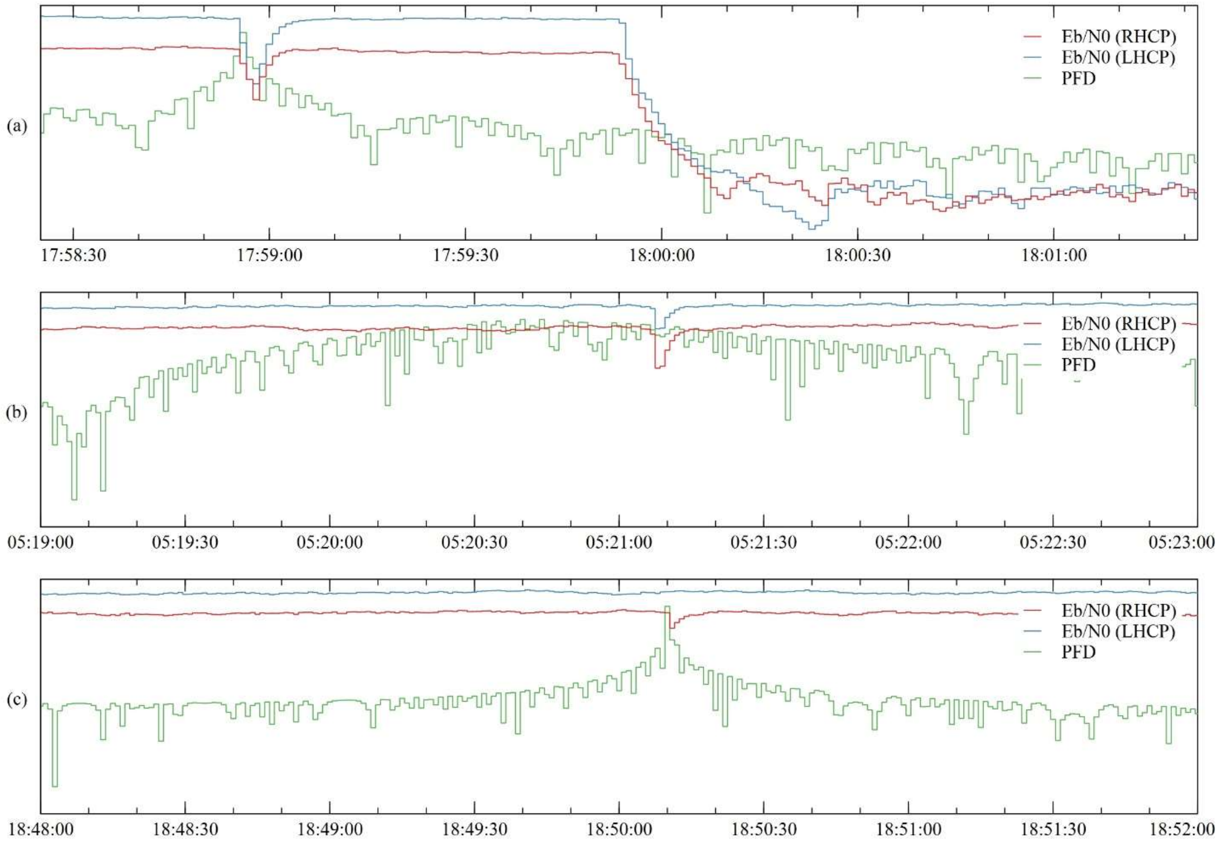

Fig. 5. Impact of RFI from Identified Candidates on E_b/N_0 and PFD of KOMPSAT-3 X-band Downlink

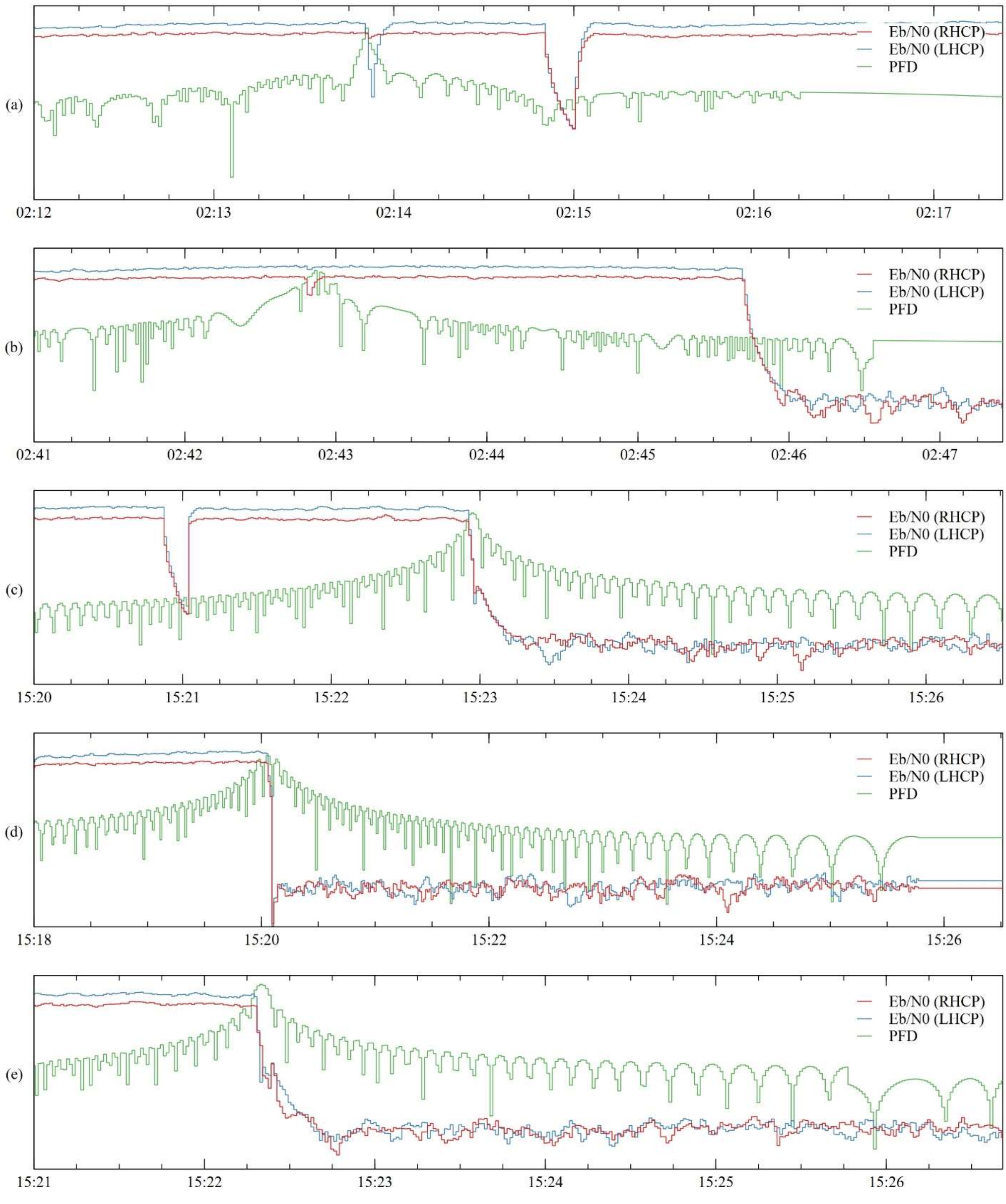

Fig. 6. Impact of RFI from Identified Candidates on E_b/N_0 and PFD of CAS500-1 X-band Downlink

6. Conclusion and Future Work

This study confirmed that the degradation in E_b/N_0 during RFI events originated from the RFI sources identified through estimation. However, some cases showed partial mismatches between the E_b/N_0 degradation periods and the PFD spikes, suggesting that the available parameters for the RFI sources were insufficient. In addition, the RFI criteria caused by these sources did not exceed the interference protection in the ITU-R SA.609 and SA.1026, indicating that the interference did not violate the RR. Given that NGEO systems do not operate in fixed orbits, the frequency of RFI occurrence is relatively low. However, estimating all possible RFI events and applying them across the full mission plan remains challenging. In the New Space era, the lack of correct system parameters, particularly those related to ES, may result in unnecessary or overly conservative constraints on mission planning and operations. Lastly, although the confirmed RFI events satisfied the criteria defined in the ITU-R SA.609 and SA.1026, the continued increase in such satellites may eventually pose a significant threat to stable space communications.

As future work, we plan to verify the estimated RFI sources by confirming the communication parameters of their associated ES with the respective administrators. We also intend to investigate the real-time usage of frequency bands allocated to the NGEO KARI Program within national coverage areas to further improve the accuracy of RFI source identification.

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