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Analysis of Radio Frequency Interference to the Deep Space Network From a Constellation of Low Earth Orbit Satellites

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Recently, many low Earth orbit (LEO) satellite constellations have been proposed as an infrastructure for data, voice, and wireless communications. Among these is Motorola's M-Star system, which uses a downlink frequency band at 37.5 to 40.5 GHz. This band overlaps the band at 37.5 to 38.0 GHz that is allocated to space research service (space to Earth). Thus, interference from M-Star to the Deep Space Network (DSN) is possible. Here we present a radio frequency interference (RFI) analysis based on simulation of the dynamic satellite constellation using the Satellite Orbit Analysis Program (SOAP). The results suggest that band sharing between the DSN and M-Star may be possible.

I. Introduction

With the increasing demands of wireless communication and the maturity of many advanced technologies, utilization of low Earth orbit (LEO) satellite constellations has become a reality. A constellation consisting of tens or even hundreds of LEO satellites can provide continuous 24-hour-a-day global coverage. In contrast to traditional geostationary communication satellites, the LEO satellite constellation has the advantages of shorter transmission delays and small, low-cost, low-power ground terminals. Although the whole system will require billions of dollars to build, launch, and operate, this cost is only a fraction of what it would cost to build a comparable terrestrial system with the same global connectivity.

The proposed Motorola M-Star system comprises a constellation of 72 LEO satellites along with the associated ground terminal equipment. Ground users will be served by very narrow spot beams (beamwidths less than 2 degrees) from the satellite constellation. M-Star is designed to provide around-the-clock data, voice, and two-way backhaul services over the area between latitude 57-degrees north and 57-degrees south. It will have double, triple, or quadruple coverage for 100, 70, or 10 percent of the time [1], respectively, over the Deep Space Network's (DSN's) three complexes located at Goldstone, California; Madrid, Spain; and Canberra, Australia.

The M-Star system plans to operate at a downlink frequency band from 37.5 to 40.5 GHz. Since the frequency band at 37.5 to 38.0 GHz also has been allocated to space research services (space to Earth) by the International Telecommunication Union (ITU) for space very long baseline interferometry (SVLBI) and Moon-to-Earth links, there exists the potential for interference from M-Star to the DSN.

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This especially is true since M-Star will provide continuous coverage with multiple satellites to each DSN location. This article provides a radio frequency interference (RFI) analysis of M-Star with respect to the 11-m antenna Deep Space Station (DSS) at Goldstone (DSS 23, located at latitude 35.16-degrees north and longitude 243.13 degrees). Similar results can be expected for the other two DSN complexes because the amounts of coverage from M-Star at these latitudes are similar.

II. Parameters and Assumptions

Tables 1 and 2 list the orbital and relevant telecommunication parameters of the M-Star system [1]. These numbers are used in our simulation and analysis.

Table 1. Orbital parameters of the M-Star system.

Parameter	Value
Number of satellites	72
Number of planes	12
Orbit altitude	1350 km
Inclination	47 deg
Argument of perigee	90 deg
Eccentricity	0.0013
Plane phasing	+25 deg
Minimum elevation angle	22 deg
Orbit period	6761 s

Table 2. Relevant telecommunication parameters of the M-Star system (satellite-to-cell-site link).

Parameter	Value
Number of communication beams per satellite	32
EIRP (clear days)	31.6 dBW
Signal frequency	37.5 GHz
Data rate	51.84 Mb/s
Modulation	QPSK
Coding	Convolutional code (1/2,7) and Reed–Solomon code (255,229)

In addition, we have made the following assumptions in running the simulation and performing the analysis:

Assumption 1: Each satellite always has a beam pointing at DSS 23 whenever DSS 23 is visible within the satellite's coverage footprint (the minimum elevation angle of the ground station is 22 degrees). This stringent condition models the worst-case interference scenario coming from M-Star.

Assumption 2: Several different ground terminals, such as the cell site terminal, the mobile telephone switching center (MTSO) terminal, and the high bit-rate terminal (HBRT), are used to access the M-Star system. Each terminal is designed for a certain link with its specific effective isotropic radiated power (EIRP), data rate, and multiple access format. It is highly unlikely that a MTSO or HBRT will be located at Goldstone; thus, we assume that a cell site is located there for this analysis. Parameters of the satellite-to-cell-site link are given in Table 2.

Assumption 3: M-Star employs dynamic power control. It uses a larger EIRP value on rainy days in order to compensate for the rain loss. Because of the desert-like weather at Goldstone, the satellite's EIRP value on clear days is used.

Assumption 4: The satellite will experience orbit precession caused by the oblateness of the Earth. This effect is more significant for LEO satellites than for medium Earth orbit (MEO) and geosynchronous orbit (GEO) satellites. M-Star satellites will not apply their thrusters to compensate for the orbit precession, and SOAP correctly models it.

Assumption 5: Signal and interference are at the same frequency: 37.5 GHz. The Doppler effect is not considered. This is the so-called cochannel interference.

III. Simulation

In order to perform the RFI analysis of M-Star with respect to DSS 23, we first have to determine the geometric configurations of the satellite constellation, the satellite orbits, the coverage areas, and the beam-pointing directions. All these quantities are dynamic functions of time. To perform such a task analytically would be very difficult and time consuming due to the complexity of the underlying physics that govern orbit motion. A powerful software tool, the Satellite Orbit Analysis Program (SOAP) developed by the Aerospace Corp., features built-in propagators that model the propagation of satellite orbits. With the use of SOAP, we are able to obtain these geometrical quantities in a straightforward fashion within hours. In addition, SOAP's visualization capability provides us with many valuable insights during the simulation process. The details of how to use SOAP to simulate different scenarios can be found in [2]. Figure 1 shows the configuration of the M-Star satellite constellation in a SOAP environment. We also show one satellite with its cone of coverage area, footprint, and a narrow beam pointing at Goldstone. For viewing clarity, the same features of other satellites are not shown.

Three scenarios being simulated are described in the following. A time step of 5 seconds, which provides adequate angle resolution in determining the off-boresight angle of the DSN antenna, is used in the simulations.

Scenario 1: DSS 23 points at a set of fixed elevation angles, such as 5, 20, 21, 22, 30, 60, and 90 degrees. The azimuthal angle is 220-degrees clockwise from north. Although this scenario may not be realistic, it provides insight regarding the relationship between the interference from M-Star with DSS 23 at different elevation angles. The simulation period is 25 hours for each different elevation angle.

Scenario 2: DSS 23 tracks the Very Long Baseline Interferometry (VLBI) Space Observatory Program (VSOP). Because VSOP is not always visible to DSS 23 (only about 30 percent of the time), the accumulated visible time of VSOP during a 1-week period is 48 hours in 14 tracking passes. This scenario is a representative interference study of the SVLBI link.

Scenario 3: DSS 23 tracks the Moon. This models a Moon-to-Earth link. Since the inclination angle of the Moon's orbit varied from 18 to 28 degrees, a median value of 23 degrees is used. Three declination angles (−23, 0, and +23 degrees) of the Moon as representative samples of the possible declination angles from −23 to +23 degrees are considered. Simulation periods range from 10 to 14 hours because the visible time of the Moon (from DSS 23) varies at different declination angles.

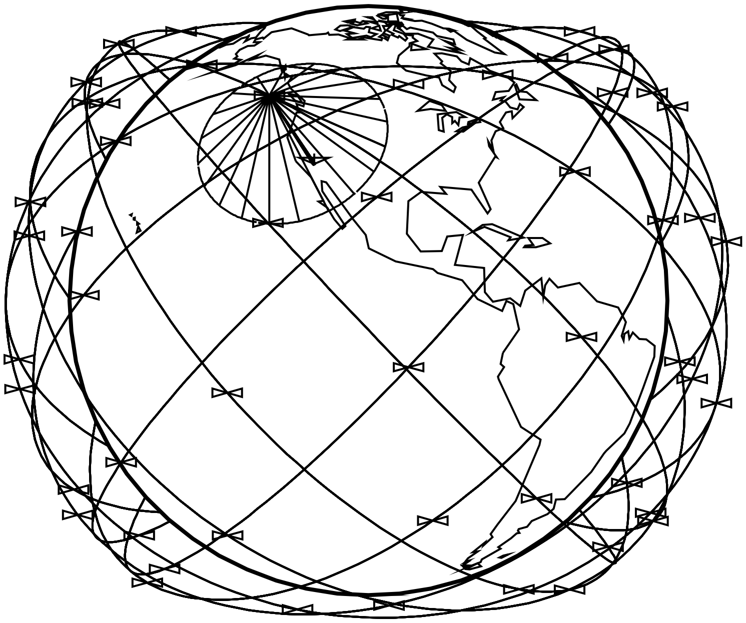

Fig. 1. Configuration of the M-Star satellite constellation shown in SOAP.

IV. Analysis and Results

An interference threshold has to be established before performing the RFI analysis. The threshold serves as a reference to be compared with the incoming interference. When the interference is above the threshold, it is called harmful interference. The interference threshold adopted in this analysis for a deep-space Earth-station receiver is −216 dBW/Hz in the carrier tracking loop when the received signal is 32 GHz [3]. This particular criterion is selected because it is an ITU standard for interference protection and simple to apply. Equation (1) calculates the interference power spectral density (PSD) in the receiver's carrier tracking loop resulting from a single M-Star satellite:

$$\begin{aligned}\mathrm{PSD(dBW/Hz)} &= \frac{\mathrm{EIRP/data\ bandwidth}}{4\pi R^2} \times A_e \\ &= \frac{\mathrm{EIRP/data\ bandwidth}}{4\pi R^2} \times \frac{\lambda^2}{4\pi} G_r(\theta) \qquad (1)\end{aligned}$$

where

$$
\begin{aligned}
\text{EIRP} &= 31.6\ \text{dBW} \\
\text{Data bandwidth} &= \text{(quadrature phase shift keying [QPSK] data rate)} \times \text{(coding rate)} \\
&= \left(\frac{51.84}{2}\right) \times \left(2 \times \frac{255}{229}\right) \\
&= 57.73\ \text{MHz}
\end{aligned}
$$

$A_e =$ effective aperture area of DSS 23 (diameter = 11 m; assume the efficiency = 0.55)

$R =$ distance from the satellite to DSS 23

$\lambda =$ wavelength

$G_r(\theta) =$ the standard antenna-gain pattern used for interference analysis [4]

$\theta =$ the angle between the DSS-23 pointing direction and the beam-arriving direction from the M-Star satellite

The values of R and θ of each satellite can be determined readily from the SOAP simulation environment and exported to files for later calculations. In Eq. (1), we take account only of the free space loss, due to its dominance over other kinds of losses, for example, atmospheric loss, pointing loss, and polarization loss. This will yield a slightly higher (more conservative) estimate of the interference PSD. Because the M-Star system may have double, triple, or even quadruple satellite coverage over DSS 23, three quantities of interest are calculated and defined as follows: Total interference is defined as the sum of interferences coming simultaneously from all interfering satellites. Maximum or minimum interference represents the strongest or the weakest component of total interference, respectively. Total interference will give the largest interference (worst case); however, the difference between total and maximum interference is small. This implies that total interference consists of one dominating component and the other much weaker ones. If we consider minimum interference, i.e., M-Star retains only the weakest beam among all interfering beams, no harmful interference would occur. The figures and tables referred to in the next paragraph all are based on total interference.

Figure 2 shows the total interference PSD calculated from the first scenario, and Fig. 3 shows the second and third scenarios. The horizontal lines in the figures indicate the -216-dBW/Hz interference threshold. Tables 3 through 5 summarize some useful statistics, such as time percentage of the harmful interference; average, maximum, and minimum duration of each harmful interference occurrence; and the average occurrence rate. The time percentage of harmful interference is defined as the total duration of all harmful interferences divided by the total visible time of the target being tracked by DSS 23. In Table 3, a dramatic drop in time percentage is observed at elevation angles below 22 degrees. This is because the satellite coverage area is a function of the minimum elevation angle (22 degrees in this case), and the satellite's pointing beams are restricted within its coverage area.

V. Conclusions

SOAP provides an excellent environment for the analysis of complex satellite constellations. It is foreseeable that there will be more such systems in the future that may pose interference threats to the DSN. Following the methodology presented here, we will be able to predict such potential interference quickly and accurately.

From the analysis of three different scenarios, we found that the percentage of harmful interference occurrence is about 0.5 percent or less of the time. The average duration of harmful interference ranges from 20 to 30 seconds. However, these results were obtained under some conservative assumptions. Relaxing the stringency of the assumptions, such as Assumption 1—namely, that every satellite has a

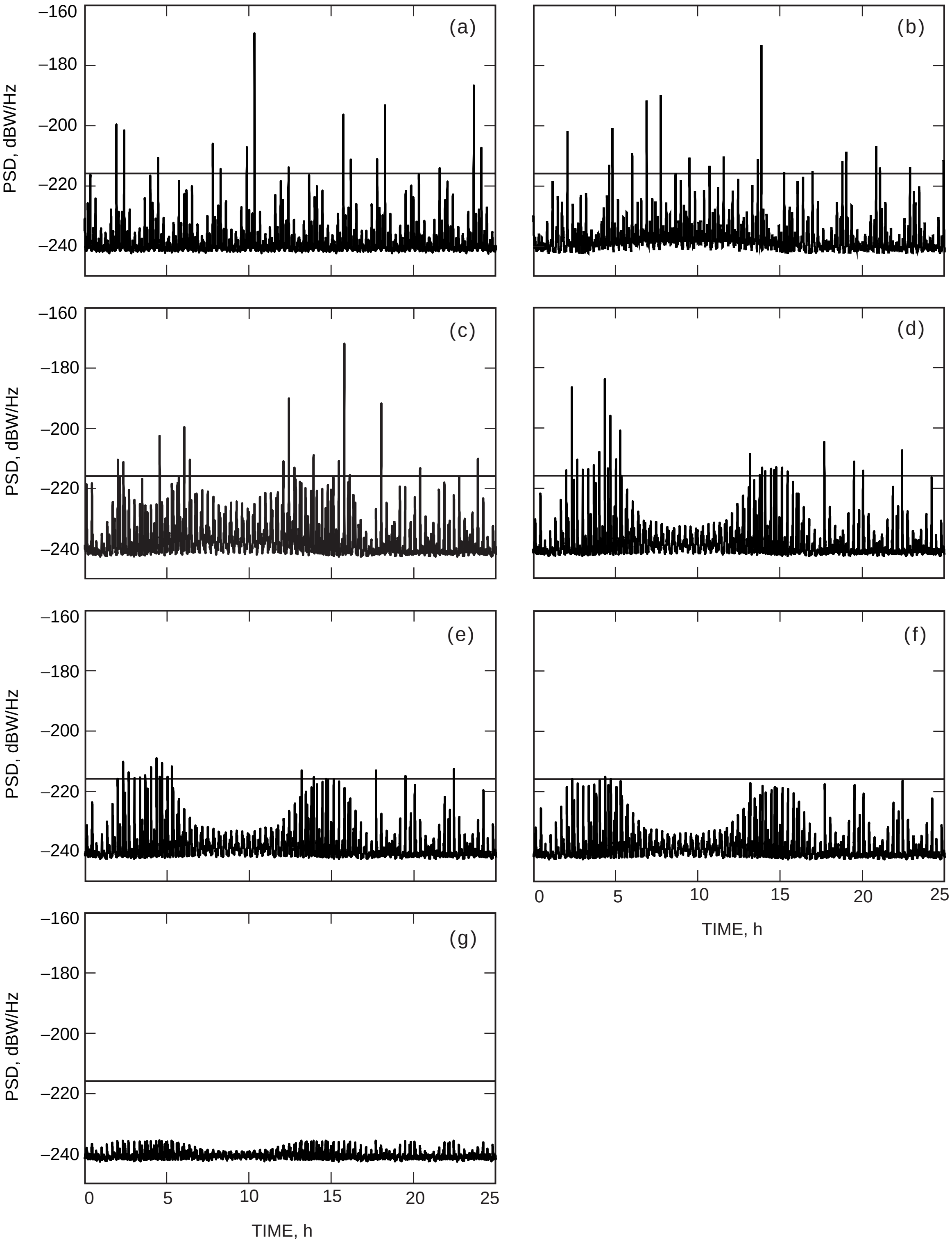

Fig. 2. Total interference at DSS 23 from M-Star when DSS 23 points at elevation angles: (a) 90 deg, (b) 60 deg, (c) 30 deg, (d) 22 deg, (e) 21 deg, (f) 20 deg, and (g) 5 deg.

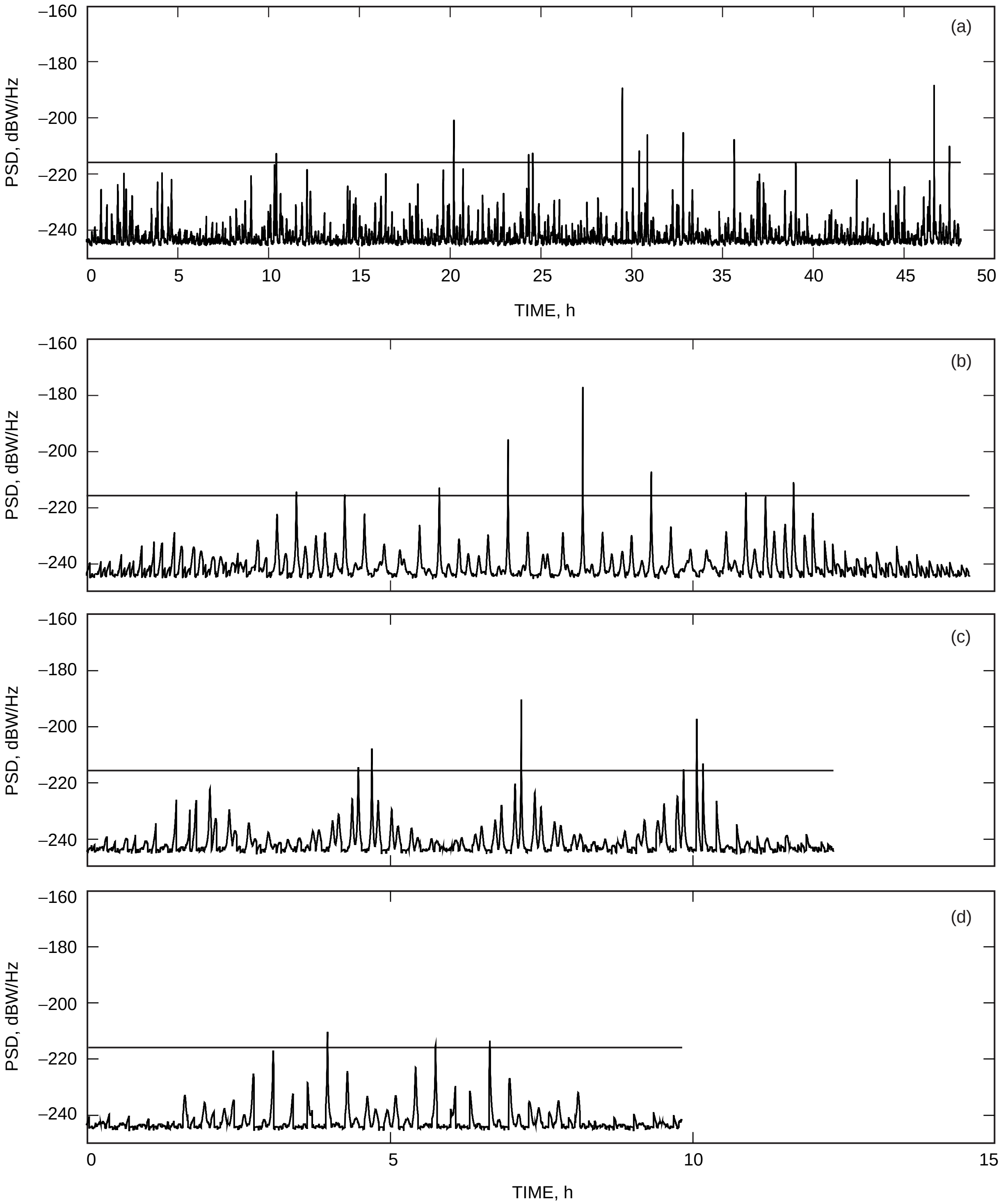

Fig. 3. Total interference at DSS 23 from M-Star when DSS 23 tracks (a) VSOP, (b) the Moon at a +23-deg declination angle, (c) the Moon at a 0-deg declination angle, and (d) the Moon at a –23-deg declination angle.

beam pointing at Goldstone—will reduce the time percentage of harmful interference. Furthermore, if M-Star can retain only the weakest beam among all interfering beams pointing at Goldstone (through coordination), the percentage can drop even to zero. Thus, it should be possible to share the 37.5- to 38.0-GHz band between space research service and M-Star.

Table 3. Harmful interference based on Scenario 1 (DSS 23 points at fixed elevation angles).

DSS 23 elevation angle, deg	Time percentage, %	Average duration of an occurrence,[a] s	Maximum duration of an occurrence,[a] s	Minimum duration of an occurrence,[a] s	Average occurrence rate, no./h
90	0.40	24.00 ± 5	30 ± 5	15 ± 5	0.6
60	0.52	23.25 ± 5	30 ± 5	10 ± 5	0.8
30	0.54	32.67 ± 5	45 ± 5	15 ± 5	0.6
22	0.57	20.20 ± 5	30 ± 5	5 ± 5	1.0
21	0.23	11.30 ± 5	25 ± 5	5 ± 5	0.72
20	0.016	5.00 ± 5	5 ± 5	5 ± 5	0.12
5	0	—	—	—	—

[a] Where the ±5 represents the 5-s time resolution used in the simulations.

Table 4. Harmful interference based on Scenario 2 (DSS 23 tracks VSOP).

Time percentage, %	Average duration of an occurrence,[a] s	Maximum duration of an occurrence,[a] s	Minimum duration of an occurrence,[a] s	Average occurrence rate, no./h
0.25	25 ± 5	40 ± 5	10 ± 5	0.35

[a] Where the ±5 represents the 5-s time resolution used in the simulations.

Table 5. Harmful interference based on Scenario 3 (DSS 23 tracks the Moon).

Declination angle of Moon, deg	Time percentage, %	Average duration of an occurrence,[a] s	Maximum duration of an occurrence,[a] s	Minimum duration of an occurrence,[a] s	Average occurrence rate, no./h
+23	0.46	26.7 ± 5	30 ± 5	25 ± 5	0.62
0	0.39	30.0 ± 5	45 ± 5	20 ± 5	0.49
−23	0.31	27.5 ± 5	35 ± 5	20 ± 5	0.4

[a] Where the ±5 represents the 5-s time resolution used in the simulations.

Acknowledgment

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References

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