Aggregate Interference Analysis of a LEO Satellite Constellation into the Radio Astronomy Observatory

Mustafa Harun Yilmaz
Institute for Telecommunication Sciences, National Telecommunications and Information Administration, Colorado, USA
Email: myilmaz@ntia.gov

***Abstract*—One mechanism to provide worldwide internet coverage is to deploy low Earth orbit satellite megaconstellations. Increasing the number of satellites in space increases the risk of harmful interference on radio astronomy observatories (RAOs). In this study, the aggregate interference induced on an isotropic RAO is investigated. Analysis is performed for a single orbit and for multiple orbits with 36 satellites on each orbital path. In all orbital path cases, aggregate interference exceeds the damaging interference threshold of -104.9 dBm (computed using (5) and (6)) which causes operational issues on the RAO.**

I. Introduction

Non-terrestrial networks (NTNs) offer worldwide internet coverage from low Earth orbit (LEO), motivated by the low latency compared to other orbits in space. To serve more users, companies deploy a few thousand satellites to LEO. Although it is a promising solution for worldwide coverage, these large constellations may cause interference to various ground stations such as a radio astronomy observatory (RAO). In the literature, interference from satellites to ground stations has been studied. Interference from non-geostationary orbit systems to geostationary systems has also been investigated [1], [2]. To solve the interference problem, spectrum sharing among NTN and terrestrial networks has been studied [3].

In this study, the aggregate interference effect of satellites in LEO on the RAO in Green Bank is investigated. The Green Bank Telescope is located in the National Radio Quiet Zone [4] in West Virginia to minimize radio frequency interference. It operates in various frequency bands ranging from 290 MHz to 115.3 GHz and bandwidths are selectable by receiver configuration [5]. Satellites operating in S-band could induce harmful interference on the RAO. In this study, three scenarios are considered: one, 36, and 72 orbits with 36 satellites in each orbital path. The interference protection criteria (IPC) for the isotropic RAO is computed as -104.9 dBW, which is also considered a damaging threshold, and it is found that the IPC is exceeded all the time in all orbital path cases.

II. System Model

The link budget calculation for NTNs is defined in [6] as carrier-to-noise ratio for a single link. Since aggregate interference over multiple links is considered in this study, the link budget per carrier is assumed to be the received interfering signal power and defined as follows:

$$p_i = \frac{p_{tx} g_{tx} g_{rx}}{l_{fs} l_a l_{sl} l_{sm} l_{ad} l_c}, \quad \text{[W]}, \tag{1}$$

Fig. 1. System with multiple orbits and satellites. Green dashed lines show the line-of-sight communication.

where p_{tx} is the satellite transmit power in Watts, g_{tx} is the satellite antenna gain, g_{rx} is the RAO antenna gain, l_{fs} is the free space path loss, l_a is the attenuation due to atmospheric gases, l_{sl} is the attenuation due to atmospheric scintillation, l_{sm} is the shadowing margin, l_{ad} is an optional degradation due to feeder link losses in transparent architecture, and l_c is the cable loss. The aggregate interference over N links is expressed as

$$I = \sum_{k}^{N} p_i^k, \quad \text{[W]}. \tag{2}$$

III. Performance Results

Satellite scenarios with single and multiple orbits are considered. Fig. 1 illustrates the satellite constellation with 72 orbits and 36 satellites on each. The ground station is the RAO with idealized isotropic antenna with a 100 m radius. Satellites in line of sight (LOS) condition to the RAO are assumed to interfere from the mainbeam to calculate the highest possible interference power, i.e., the worst-case interference scenario, due to the beamforming antennas used by the satellites. In [7], free space (L_{fs}) and atmospheric losses (L_a) are given as

$$L_{fs} = 32.45 + 20\log(f_c) + 20\log(d), \quad \text{[dB]} \tag{3}$$

$$L_a = \frac{A_{zenith}(f_c)}{\sin(\alpha)} \quad \text{[dB]} \tag{4}$$

where f_c is the center frequency in GHz, d is the slant distance in meters, A_{zenith} is the zenith loss and α is the elevation angle in degrees. The interference threshold IPC_{pfd} is given as -79 dBW/m^2 in terms of power flux density (PFD) [8]. The effective area of the aperture of the telescope is

$$A_{eff} = \frac{\lambda^2 g_{rx}}{4\pi} \quad [\mathrm{m}^2], \tag{5}$$

where λ is the wavelength. Finally, the IPC_{agg} is

$$IPC_{agg} = IPC_{pfd} + 10\log_{10}(A_{eff}) \quad [\mathrm{dBW}] \tag{6}$$

With (6), the aggregate interference power threshold is found to be -104.9 dBW. The values of all parameters used in this simulation are shown in Table I.

TABLE I
SIMULATION PARAMETERS

Simulation Parameters	Parameter Value
Frequency	1665 MHz
RAO coordinates (Lat/Long)	[38.4331211,-79.839835]
RAO Antenna Gain	0 dBi [1]
Shadowing margin	0 dB
Satellite transmit power	20 dBW
Satellite antenna gain	38 dBi
Altitude of satellites	340 km above Earth
Cable loss	0 dB
Additional loss	0 dB
Scintillation loss	2.2 dB

Fig. 2 shows the cumulative distribution function (CDF) of interference power for the three different scenarios. In the single orbit case, usually a single satellite is in LOS condition with the RAO, occasionally two satellites are in LOS. Increasing the number of orbits results in up to six satellites on 72 orbits (Fig. 1) being visible by the RAO at the same time. When aggregate interference is calculated, the received power of all these satellites in a LOS condition with the RAO is summed over all those links as defined in (2). Although most of the time a single satellite is in LOS condition in the single orbit case, the interference values fluctuate between $-100\,dBW$ and $-91\,dBW$. Since the slant distance changes based on the position of the satellite, the free-space pathloss value changes, and so does the received interfering power, p_i, in (1). On the other hand, while satellites orbit the Earth, their orbital path also progresses around the Earth from East to West. Due to this motion, some satellites will occasionally be at the nadir position which minimizes pathloss and results in larger possible values of interference power. As seen in Fig. 2, when the number of orbits and satellites increases, the aggregate interference power also increases due to the higher number of satellites visible to the RAO at the same time. In all scenarios, the damaging IPC threshold is exceeded. Even with a single orbital case, the lowest interference power is 4.9 dB higher than the threshold. Because these constellations are anticipated to be composed of a few thousand satellites

[1]The antenna gain of the Green Bank Telescope is 64.83 dBi, this study considers the effect of aggregate interference on an idealized isotropic receiver at 0 dBi

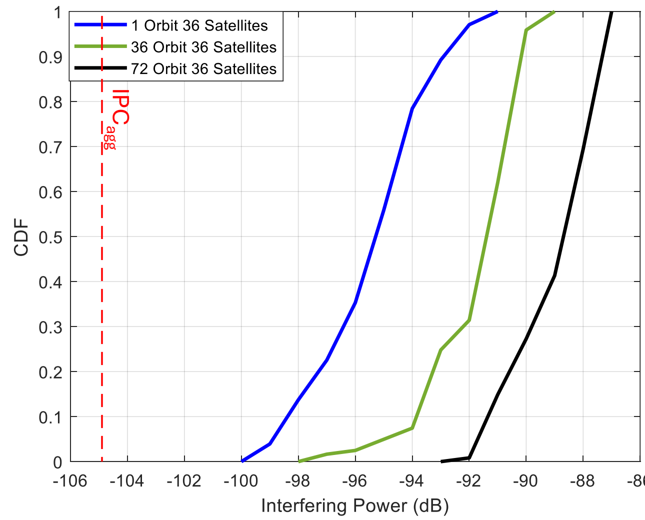

Fig. 2. Aggregate interference results when multiple satellites are interfering with RAO

in LEO, they would degrade the operations of the RAO all the time in the case of interference from the mainbeam of the satellites.

IV. CONCLUSION

With the increasing number of satellites in LEO, interference from those satellites affects the operations of the RAO. In this study, the aggregate interference power of satellites in LEO induced on a RAO is investigated. It is found that in all orbital path cases, the aggregate interference exceeds the IPC of -104.9 dBW all the time. Since the aim is to analyze the worst case scenario, interference from the mainbeam of the satellites is considered. In a future study, we will investigate the case where the satellite beams are steered to prevent mainbeam interactions. Instead, interference from sidelobes will be analyzed.

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