Inline Interference Mitigation Techniques for Spectral Coexistence of GEO and NGEO Satellites

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The requirement of low latency for real time systems and high demand of broadband data are leading to the rapid deployment of Low Earth Orbit (LEO)/Medium Earth Orbit (MEO) satellite systems in several frequency bands. When the number of usable non-geostationary (NGEO) satellites i.e., LEO/MEO in space increases, the need for frequency coexistence between the NGEO satellite systems with the already existing geostationary (GEO) satellite networks increases rapidly. In this context, it is crucial to explore interference mitigation techniques between GEO and NGEO systems in order to allow their spectral coexistence. More specifically, in the coexistence scenario of GEO and NGEO satellite networks, in-line interference may be a serious problem and it arises whenever an NGEO satellite passes through a line of sight path between a GEO earth station and a GEO satellite. In this paper, we carry out interference analysis between GEO and NGEO systems considering the case of O3b satellite systems and propose an adaptive power control technique for both the uplink and the downlink coexistence scenarios in order to mitigate the in-line interference. Furthermore, we provide several cognitive solutions for mitigating the in-line interference.
***Index Terms*: Satellite Communications, Cognitive Radio Techniques, Dual Satellite Coexistence, O3b satellites**

I. Introduction

Several Satellite Communications (SatComs) systems have been proposed in the literature for provision of fixed, mobile, interactive and personal services, adopting Geostationary (GEO) and Non-geostationary (NGEO) orbits such as Low-altitude Earth Orbits (LEO) and Medium-altitude Earth Orbits (MEO). Next generation satellite systems require significantly high spectral efficiency to address the spectrum scarcity problem and different satellite systems need to coexist within the same spectrum in order to achieve this objective. In this context, cognitive SatComs is a promising candidate in order to explore different opportunities for the spectral coexistence of two satellite networks [1]. GEO satellites utilize a circular orbit above the earth's equator maintaining the same position relative to the earth's surface whereas NGEO satellites generally have orbits with varying altitudes and positions. The main advantages of NGEO satellites are reduced free space attenuation, small propagation delay and the reduced cost of in-orbit injection per satellite [2]. Recently, the Others Three Billion (O3b) network has proposed to launch O3b satellites in the MEO of 8062 km in order to improve the round trip latency as compared to GEO orbit. The O3b network proposes to use parts of the Ka band (uplink: 27.5-30.0 GHz and downlink: 17.8-20.2 GHz) that are also being used by the GEO networks. Furthermore, Iridium NEXT with the constellation of 66 cross-linked LEO satellites in six orbital planes intersecting over the north and south poles is about to replace the Iridium's current satellite constellation in near future [3]. In the coexistence scenarios of GEO and NGEO networks, in-line interference may be a serious problem and it arises whenever an NGEO satellite passes through a line of sight path between an earth station and the GEO satellite since the earth station which is in-line with GEO and NGEO satellites may receive and create interference through its main beam. In this context, exploring efficient techniques to mitigate the in-line interference is a highly relevant and challenging problem for the spectral coexistence of GEO and NGEO satellite networks [3, 5, 20].

Cognitive communications is considered a promising candidate for allowing the coexistence of different wireless networks. In the context of SatComs, recent work exploiting spectrum sharing opportunities includes [1, 6–15]. Furthermore, the contributions in [1, 7, 8, 12, 14] focus on hybrid coexistence scenario of satellite and terrestrial systems and the contributions in [6, 9, 11, 13, 15] address dual satellite coexistence scenarios. The interference scenario in a satellite system is different from that of the terrestrial systems due to the presence of the on-board antenna which acts as a spatial filter [2]. Cochannel interference mainly arises due to the presence of sidelobes in the on-board antenna radiation diagram i.e., non-ideal angular selectivity of the spotbeams. In NGEO satellite systems, the relative position of the cochannel spots changes over time due to the constellation dynamics. In [2], several techniques such as spot turnoff, intraorbital plane frequency division and interorbital plane frequency division have been identified in order to avoid or minimize the cochannel interference between GEO and NGEO systems.

I.A. Scenario and Contributions

The coexistence of NGEO and GEO Fixed Satellite Service (FSS) satellites can enhance the overall spectral efficiency of satellite systems by making efficient use of allocated spectrum in both temporal and spatial domains. Different coexistence techniques can be explored in the normal forward/return mode and reverse mode scenarios [1]. Depending on the coexistence in forward or reverse modes, the following scenarios can be considered.

- LEO/MEO and GEO coexistence in the Ka band with forward band sharing (GEO forward link, LEO/MEO forward link)
- LEO/MEO and GEO coexistence in the Ka band with reverse band sharing (GEO forward link, LEO/MEO return link)
- LEO/MEO and GEO coexistence in the Ka band with forward band sharing (GEO return link, LEO/MEO return link)
- LEO/MEO and GEO coexistence in the Ka band with reverse band sharing (GEO return link, LEO/MEO forward link)

The International Telecommunication Union (ITU) recommendation ITU-R S.1431 provides different mitigation techniques in order to avoid the in-line interference between two NGEO satellites such as satellite diversity, satellite selection strategies, frequency channelization etc. Furthermore, ITU-R S.135.2 provides different strategies such as GEO arc avoidance based on the latitude and based on the discrimination angle between NGEO satellite and the GEO arc. For the GEO arc avoidance based on the latitude, an Exclusion Zone (EZ) of θ° needs to be defined with respect to the equatorial plane and for another method based on discrimination angle, the minimum discrimination angle α° is needed. However, it remains an open challenge to find out the optimum values of θ° and α°. With the knowledge of these values, different mitigation strategies such as satellite switching, spot turn off etc. can be applied. Furthermore, it's highly possible to operate NGEO earth stations within the GEO EZ by applying a power control technique in such a way that the aggregate interference towards the GEO satellite is below the interference threshold of the GEO satellite.

The O3b networks has proposed the O3B constellation of 12 to 20 satellites in a circular MEO at a distance of about 8062 km from the earth. Out of which four satellites have been already been launched in the operational orbits. The round trip delay of O3b satellite is 120 ms as compared to 500 ms of the GEO. This becomes highly advantageous for enhancing the quality of telephone calls and data throughput using satellite networks. The main advantages of O3b networks are low latency, high capacity of 1.2 Gbps, competitive pricing, easily and quickly deployable structure [22]. In case of maritime communications, the beams of O3b satellites can follow the movement of the ship in order to optimize the coverage. For this purpose, the ship requires two tracking antennas, each tracking a different satellite, and switching from one to the other as the satellites rise and set. The beam footprints have a diameter of about 600 km on the earth surface between 45° North and 45° South and can be dynamically steered as the satellite moves in order to cover the required areas and skip over the unpopulated areas.

It should be noted that as the number of usable NGEO satellite systems in space increases, the need for frequency coexistence between the NGEO satellite systems with the already existing satellite networks increases rapidly. This coexistence can be in space and time domains or any other possible domains such as polarization, radiation pattern etc. The interference environment generated by NGEO satellite systems is not completely known yet and the studies have been conducted with the purpose of examining the feasibility of frequency sharing between other services and NGEO satellite systems [16, 17, 19, 20].

Although the coexistence of GEO and NGEO satellites have been discussed in the literature by analyzing the interference mechanism between these systems by using different simulation software such as Visualyse [18], our idea in this paper is to propose cognitive techniques which will allow these two systems to coexist with better interference management. We consider the scenarios of both GEO and NGEO networks operating in either the normal return mode or the normal forward mode with the GEO satellite as the primary and the NGEO satellite as the secondary. Furthermore, we consider the coexistence of a GEO satellite link operating in the Ka band and an O3b satellite link as an example of NGEO satellite link in our analysis. The main problem which arises in the coexistence of the GEO and NGEO networks is the in-line interference event as mentioned earlier. Although this event can be predetermined and avoided by using proper planning considering the constellation geometries, the performance of the primary system may be affected due to less dynamicity of these methods. Furthermore, the Quality of Service (QoS) of the NGEO system may not be guaranteed while trying to mitigate in-line interference with these static methods. In this context, we propose adaptive power control at the NGEO terminal for the uplink transmission and at the NGEO satellite for the downlink transmissions. In the proposed adaptive power control scheme, the required transmission power is determined to control the interference towards the victim receivers i.e, GEO satellite in the uplink transmission and the GEO earth station terminal in the downlink transmission, taking into account of the interference threshold of the victim receiver as well as the required QoS for the NGEO link. Furthermore, we propose different coordinated and uncoordinated cognitive techniques which can be explored further for their practical feasibility.

II. Spectral Coexistence of NGEO and GEO Satellites

Currently, according to ITU RR No 5.523A, NGEO satellite systems can use the bands 17.8-18.6 GHz, 19.7-20.2 GHz, 27.5-28.6 GHz and 29.5-30 GHz in primary basis by respecting the Effective Power Flux Density (EPFD) limits in order to protect the GEO systems. It can be noted that the adjacent bands 18.8-19.3 GHz and 28.6-29.1 GHz bands have been allocated to GEO satellites in the primary basis. By using suitable cognitive techniques, these bands can be shared by GEO and NGEO systems for enhancing the spectral efficiency of satellite systems.

The O3B network proposes to use parts of the Ka band that are also used by GEO networks. It can be observed that the frequencies used in the O3B network are in the following bands [21]: uplink: 27.5-30.0 GHz and downlink: 17.8-20.2 GHz. Since the frequencies in this range have been already allocated to GEO networks, a number of interference paths exists while sharing these bands by the O3b networks. For proper sharing of these bands, it should be guaranteed that the EPFD limits within the specified band do not exceed the prescribed limit in by ITU-R.

It can be noted that for GEO satellite networks serving earth stations at high latitudes, the occurrence of in-line even never occurs, therefore, not resulting in harmful interference to the GEO networks. However, for GEO satellite networks serving earth stations near the equator, it can be observed that there could be a potential problem as the O3B satellite may directly fall in-line between the GEO satellite and an earth station located on the equatorial plane [21].

The radiation patterns of the earth station antennas play an important role in interference analysis and mitigation between two satellite systems. We assume that the earth stations are equipped with parabolic reflector type antennas with a radiating aperture. For an earth station

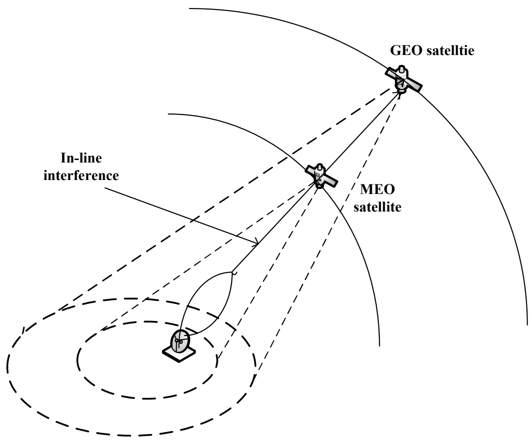

Figure 1: In-line interference in normal return mode (The SAT terminal can be MEO/GEO terminal and interference path can be towards GEO/MEO satellites respectively)

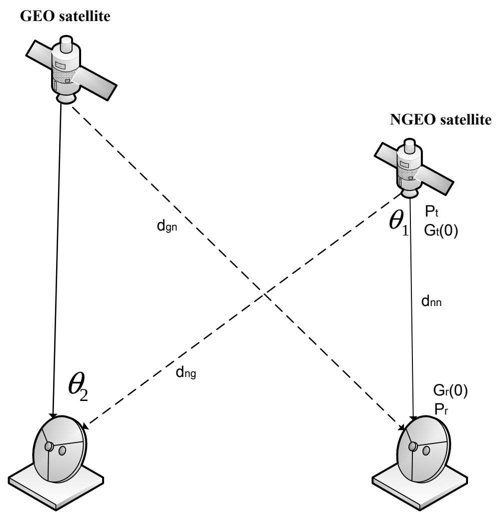

Figure 2: Desired and interference links in the downlink coexistence of GEO and NGEO satellite networks

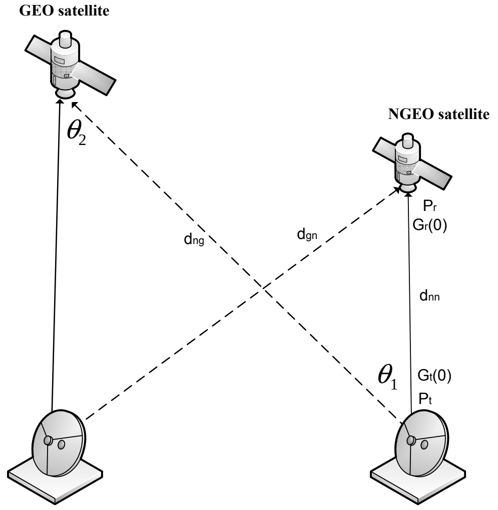

Figure 3: Desired and interference links in the uplink coexistence of GEO and NGEO satellite networks

antenna, the important parameters for characterizing the radiation of the main lobe are the gain, the angular beamwidth and the polarization isolation. The recommendation ITU-R S.672-4 provides the satellite antenna radiation pattern for the GEO FSS satellites and ITU-R S.1528 provides the satellite antenna radiation patterns for NGEO FSS satellites operating below 30 GHz.

II.A. Downlink Coexistence Analysis

In this scenario, we consider both the GEO and NGEO satellite links operating in the normal forward mode as shown in Fig. 2. There exist the following two interference links: (i) from the NGEO satellite to the GEO earth station and (ii) from the GEO satellite to the NGEO earth station. We consider that the GEO satellite is already in operation and the NGEO satellite link is to be deployed in the same spectrum. In this case, the link budget of the NGEO link can be adjusted by taking into account of the interference caused by the GEO satellite to the NGEO link. To make the analysis simpler, we consider a single NGEO satellite operating in the same frequency as that of the GEO satellite [a].

II.A.1. Problem Statement

In this work, we target to solve the following issues for the considered downlink coexistence scenario.

- The downlink transmission from the NGEO satellite may cause interference to the receiver of the GEO earth station. The value of interference to noise ratio i.e., I/N at the GEO earth station should not exceed the tolerance level of I/N.
- The sum rate of the NGEO satellite link should be sufficient to achieve the desired QoS. Increasing the transmit power at the NGEO satellite may enhance the quality of the NGEO link but it may cause interference to the GEO link operating in the same frequency.
- Furthermore, the power on the onboard unit of the NGEO satellite is limited. Therefore, it is necessary to minimize the transmitted power while satisfying the above two conditions.

II.A.2. Proposed Power Control in the downlink

Let P_{tns} be the transmit power of the NGEO satellite and W be the transmission bandwidth. Let θ_1 be the off bore-sight angle of the transmitter (NGEO satellite) in the direction of the receiver and θ_2 be the off bore-sight angle of the receiver (GEO earth station) in the direction of the transmitter. We consider G_{tns} be the gain of the transmit antenna at the NGEO satellite and the G_{rne} be the gain of the receive antenna at the NGEO earth station. It should be noted that the gain is a function of the off bore-sight angle and it's maximum at the bore-sight angle i.e., $G_{tns}(0)$ represents the maximum gain of the transmit antenna of the NGEO satellite and $G_{rne}(0)$ denotes the maximum gain of the receive antenna of the NGEO earth station. Furthermore, we consider d_{nn} to be the distance between the NGEO station and the NGEO satellite and d_{ng} be the distance between the NGEO satellite and the GEO earth station. The received power at the NGEO earth station can be written as:

$$P_{rne} = P_{tns}(d_{nn}) G_{tns}(0) G_{rne}(0) \frac{\lambda^2}{4\pi d_{nn}^2}, \tag{1}$$

where $P_{tns}(d_{nn})$ is the transmit power required to close the link when the distance between the NGEO station and the NGEO satellite is d_{nn}. The expression for Carrier to Noise ratio (C/N) at the NGEO Earth station can be expressed as:

$$C/N = \frac{P_{rne}}{KT_r W} = \frac{P_{tns}(d_{nn}) G_{tns}(0) G_{rne}(0)}{KT_r W} \frac{\lambda^2}{4\pi d_{nn}^2}, \tag{2}$$

[a]However, the case of the presence of multiple NGEO stations can be straightforwardly incorporated in the analysis.

where $K = 1.38 \times 10^{-23} W/(Hz.K)$ is Boltzmann's constant, T_r is the receive noise temperature of the receive antenna. Furthermore, the interference to noise ratio (I/N) at the GEO Earth station due the presence of NGEO link can be written as:

$$I/N = \frac{P_{tns}(d_{nn}) G_{tns}(\theta_1) G_{rge}(\theta_2)}{K T_r W} \frac{\lambda^2}{4\pi d_{ng}^2}, \tag{3}$$

where $G_{tns}(\theta_1)$ and $G_{rge}(\theta_2)$ are gains of the transmit antenna at the NGEO satellite towards the θ_1 direction (from the boresight direction) and of the receive antenna at the GEO Earth station towards the θ_2 direction (from the boresight direction). In order to address the considered problems, the following optimization problem can be formulated:

$$\begin{aligned} &\min P_{tns}(d_{nn}) \\ \text{subject to } & C/N \geq C_0/N_0, \\ & I_{\text{GEO}} \leq I_{th}, \end{aligned} \tag{4}$$

where I_{th} is the tolerable interference threshold of the GEO earth station. The above optimization problem can also be written in the following form.

$$\begin{aligned} &\min P_{tns}(d_{nn}) \\ \text{subject to } & \frac{P_{tns}(d_{nn}) G_{tns}(0) G_{rne}(0)}{K T_r W} \frac{\lambda^2}{4\pi d_{nn}^2} \geq C_0/N_0 \\ & \frac{P_{tns}(d_{nn}) G_{tns}(\theta_1) G_{rge}(\theta_2)}{K T_r W} \frac{\lambda^2}{4\pi d_{ng}^2} \leq I_{th}/N_0. \end{aligned} \tag{5}$$

Considering the noise temperature does not change over the time at transmit and receive antennas i.e., noise power $N = N_0 = K T_r W$ remains same, the above problem can be modified into the following.

$$\begin{aligned} &\min P_{tns}(d_{nn}) \\ \text{subject to } & P_{tns}(d_{nn}) G_{tns}(0) G_{rne}(0) \frac{\lambda^2}{4\pi d_{nn}^2} \geq C_0 \\ & P_{tns}(d_{nn}) G_{tns}(\theta_1) G_{rge}(\theta_2) \frac{\lambda^2}{4\pi d_{ng}^2} \leq I_{th}. \end{aligned} \tag{6}$$

II.B. Uplink Coexistence Analysis

In this scenario, we consider the coexistence of GEO and NGEO links with both operating in normal return mode as shown in Fig. 3. There exist the following two interference links: (i) from NGEO earth station to the GEO satellite and (ii) from GEO earth station to the NGEO satellite.

II.B.1. Problem statement

We study the following problems under this scenario.

- Since the GEO system is already deployed system and should be protected from the interference caused by the reuse of its operating frequencies, we consider the interfering link between the NGEO earth station to the GEO satellite. In this context, the interference from the NGEO earth station towards the GEO satellite should be below the interference constraint of the GEO satellite.

- When the NGEO link is operating in the spectrum used by the GEO satellite, the NGEO link should provide sufficient QoS to its users while guaranteeing the primary link protection.

II.B.2. Proposed Power control in the uplink

We formulate the following feasibility problem under this scenario:

$$\max_P R = \begin{cases} log(1 + C/N), & C/N \geq C_0/N_0 \\ 0, & C/N < C_0/N_0 \end{cases}$$
$$\text{subject to } I_{GEO} \leq I_{th}, \quad (7)$$

where the expression for C/N can be written as:

$$C/N = \frac{P_{rns}}{KT_rW} = \frac{P_{tne}(d_{nn})G_{tne}(0)G_{rns}(0)}{KT_rW}\frac{\lambda^2}{4\pi d_{nn}^2}, \quad (8)$$

where P_{rns} denotes the received power at the NGEO satellite, P_{tne} denotes the power transmitted by the NGEO earth station.

It can be noted that if the link budget is not enough to close the link, the terminal can not transmit anything and does not achieve any rate. More specifically, if $C/N < C_0/N_0$, the signal received at the NGEO satellite is not sufficient to close the link budget. In this case, although the terminal transmits some power, there is no achievable rate and just the resource is wasted. In this case, it's better to switch the terminal transmission or switch the transmission to other NGEO satellites which have better link condition.

In the above problem, firstly, the feasibility is analyzed based on whether the condition $C/N \geq C_0/N_0$ is fulfilled or not. If this condition is satisfied, then the problem can be considered to be feasible, otherwise this problem becomes infeasible. This feasibility condition can be checked by carrying out the link budget analysis of the interfering link between the GEO earth station to the NGEO satellite. If the problem becomes feasible, the feasibility checking problem in (7) can be reduced to the following optimization problem.

$$\max_P \hat{R} = log(1 + C/N)$$
$$\text{subject to } I_{GEO} \leq I_{th}, \quad (9)$$

where I_{GEO} denotes the interference from the NGEO earth station towards the GEO satellite and is given by

$$I_{GEO} = P_{tne}G_{tne}(\theta_1)G_{rgs}(\theta_2)\frac{\lambda^2}{4\pi d_{gn}^2}, \quad (10)$$

where P_{tne} denotes the transmitted power of the NGEO earth station, $G_{tne}(\theta_1)$ denotes the gain of the transmit antenna of the NGEO earth station in the direction of θ_1, $G_{rgs}(\theta_2)$ denotes the gain of the receive antenna of the GEO satellite and d_{gn} denotes the distance between the GEO satellite and the NGEO earth station.

III. Other Cognitive Approaches

III.A. Coordinated Approach

The main concept behind this approach is that the coordination between GEO and O3b networks can facilitate spectrum sharing between two networks. The GEO gateway station and the O3b gateway station can be connected with the help of a high speed signalling link (i.e., microwave, optical fiber). In terms of the cognitive scenario, we consider multibeam GEO satellite link as the primary and the O3b satellite link as the secondary since GEO satellite is already deployed in this spectrum. We consider the GEO satellite to be a multibeam satellite. With the help of the signalling link between the gateways, the O3b gateway can be aware of the beampatterns of the GEO satellite. However, the beampattern of the O3B satellite changes over the time. Since O3B gateway has the knowledge of GEO beampattern, it can automatically select its frequency of operation not to overlap with the in-line GEO beam. If there are no more free frequencies available, the O3b can switch off its transmission on that beam when the beam passes through the the in-line center of the GEO beam. In this way, with the help of coordination between different gateways, the harmful in-line interference can be mitigated. Furthermore, based on coordination and synchronization between two systems, cognitive beamhopping system as proposed in [15] can be applied.

III.B. Exclusion Zone plus Power Control Approach

By finding out the proper exclusion region for the GEO earth station, the interference caused by the NGEO systems to the GEO station can be mitigated by allowing them to operate outside the EZ. Furthermore, the interference caused by the NGEO systems to the GEO satellite can be mitigated by defining the proper exclusion angle and applying the techniques such as switching, turn-off etc. when NGEO satellites enter into the GEO exclusion angular region. However, as the number of NGEO systems increases, the above techniques do not provide better solution due to the requirement of higher spectral efficiency. In this context, different levels of EZ can be defined based on the level of interference between two systems. In the regions where interference level is too high, the only way to mitigate is either by switching transmission to another NGEO satellite or turning off the transmission. For other regions, we can apply power control to mitigate interference as described in the previous section. By combining these two approaches, the spectral efficiency can be enhanced than that of the spectral efficiency obtained by using only single method.

III.C. Dynamic Approach

In this approach, we consider O3B networks and GEO links working in the normal return mode. We note that VSAT transmit-receive terminals can use the same antenna for transmission and reception purposes. We can assume similar types of terminals to be used in O3b gateways/user terminals. The concept is that the in-line interference is detected during the reception phase and the terminal does not transmit in its transmission phase until the in-line interference in the reception link does not fall below the predefined threshold. In this approach, either the O3B gateway or the terminal should be equipped with some intelligent sensor which can sense the presence of the in-line interference. As soon as it is aware of the in-line interference, it can switch off its transmission dynamically.

IV. Numerical Results

For our simulation purpose, we analyze the gain patterns of GEO/NGEO earth station terminals and the GEO/NGEO satellites using relevant ITU-R recommendations. In the following subsections, we present results for the proposed power control technique for the uplink and downlink coexistence scenarios considering flat-earth approximation [b]. Furthermore, we consider the worst case interference scenario by considering both the GEO and NGEO earth stations to be located in the equatorial plane.

IV.A. Uplink analysis

We consider the coexistence of a GEO and an NGEO link, both operating in the normal return mode. As described in the earlier section, we tackle the problem of link feasibility analysis and adaptive power control to maximize the rate of the NGEO link.

Figure 4 shows the transmit power of the NGEO Earth station versus off-axis angle. The values of transmit power for different off-axis angles were obtained by solving the optimization problem given by (9). The values of interference threshold i.e., I_{th} were considered to be -150 dBW and -170 dBW. From the figure, it can be noted that when the in-line event occurs i.e., when the NGEO

[b] The exact analysis of interference between GEO and NGEO networks needs a 3D model and in this paper, we consider the flat-earth approximation for the sake of simplicity. However, the proposed techniques are applicable for the real practical scenarios as well.

earth station is in-line with the GEO and NGEO satellites, the transmit power of the NGEO station should be decreased and it can be increased as we go away from the boresight direction in order to maximize the rate of the secondary link.

Figure 5 shows the SINR versus off-axis angle for the considered uplink coexistence scenario. This variation in the SINR comes from the fact that the NGEO satellite is moving over time and the interfering signal received by it depends on the angular position with respect to the beampattern of the GEO earth station terminal. It should be noted that the value of SINR is the lowest when the GEO Earth station terminal falls in the in-line position of the NGEO satellite. Let us consider the minimum required value of SINR $i.e., \mathrm{SINR_{min}}$ to close the NGEO link as 6 dB [c]. From the figure (Fig. 5), it can be noted that for the interference threshold value of $I_0 = -170dBW$, the SINR received at the NGEO link is not sufficient to close the link in the range between $\pm 2.5°$ of the maximum gain position and hence the problem in (7) is not feasible within this angular region. Beyond this region, the SINR is sufficient to close the NGEO link and the feasibility check problem in (7) reduces to the optimization problem in (9). It should be noted that this feasible range depends on the allowable interference threshold at the GEO satellite. Furthermore, we present the plot of sum-rate of the NGEO link versus off-axis angle in Fig. 6. From the figure, it can be noted that the achievable sum-rate near to the boresight direction is very low and it increases as the off-axis angle is increased.

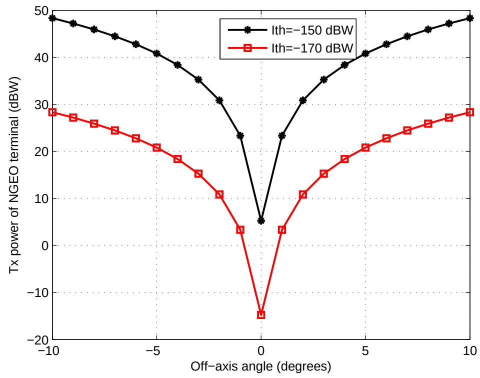

Figure 4: Transmit power of the NGEO earth station terminal for the considered uplink coexistence

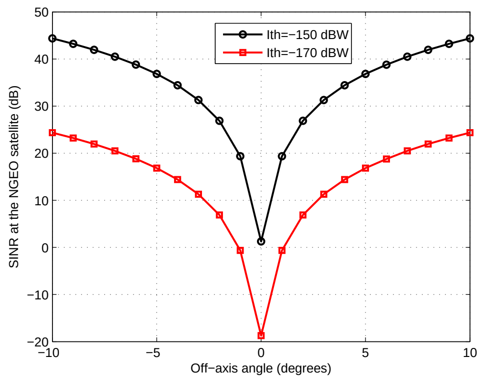

Figure 5: SINR at the NGEO satellite for the uplink coexistence scenario of GEO and NGEO links

IV.B. Downlink analysis

For the downlink coexistence scenario, we solve the optimization problem given by (6). Figure 7 shows the SINR versus off-axis angles for this scenario. In these simulation results, the values of interference threshold and the desired carrier power were considered to be -150 dBW and -105 dBW

[c] In practice, more precise value of $\mathrm{SINR_{min}}$ can be obtained from standards or the regulatory constraints for a particular NGEO satellite system

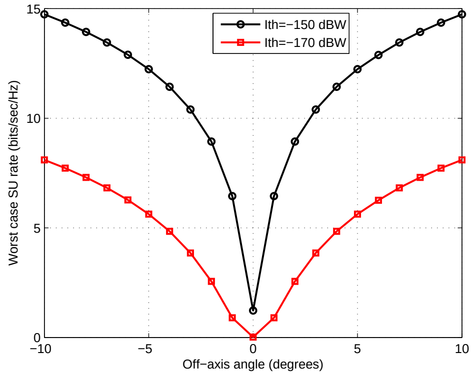

Figure 6: SU rate for the uplink coexistence scenario of GEO and NGEO links

respectively. The optimum value of power was found to be 12.2747 dBW. The NGEO satellite was considered at an angular distance of 5° from the boresight direction (0°) of the main beam of the GEO satellite. Figure 8 presents the worst case SU rate versus off-axis angle. From the figure, it can be observed that the worst case SU rate slightly increases as we move away from the boresight direction and remains more or less constant beyond 5°. The detailed link budget parameters, gain expressions, further results and future issues in this domain can be found in [23].

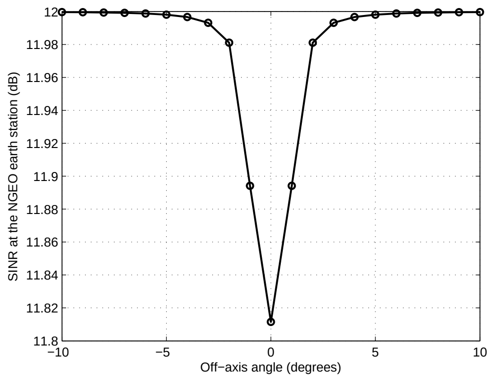

Figure 7: SINR at the NGEO earth station for the downlink coexistence scenario of GEO and NGEO links ($I_{th} = -150dBW$,$C_0 = -105dBW$)

V. Conclusion

In this paper, the spectral coexistence scenario of a GEO link and an NGEO link operating in the Ka band has been considered. An adaptive power control technique has been proposed at the NGEO terminal for the uplink transmission and at the NGEO satellite for the downlink transmission in order to mitigate the in-line interference which may arise whenever an NGEO satellite passes through a line of sight path between an earth station and the GEO satellite. The proposed technique adapts the transmit power of the NGEO satellite/terminal in order to satisfy the desired QoS of the NGEO link while respecting the interference constraint of the GEO link. Moreover, several cognitive approaches such as coordinated, dynamic and combined have been proposed in order to mitigate the in-line interference.

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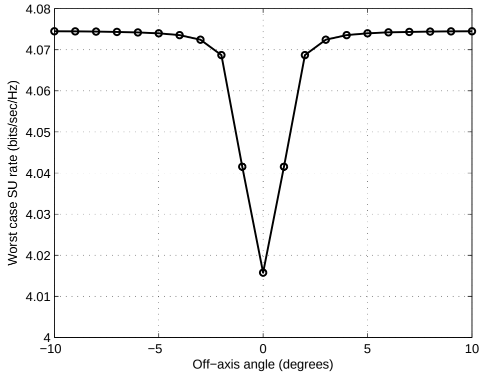

Figure 8: SU rate for the downlink coexistence scenario of GEO and NGEO links ($I_{th} = -150dBW$,$C_0 = -105dBW$)

References

[1]S. K. Sharma, S. Chatzinotas, and B. Ottersten, "Satellite cognitive communications: Interference modeling and techniques selection," in *6th ASMS/SPSC Conf.*, Sept. 2012.

[2]F. Vatalaro, G. Corazza, C. Caini, and C. Ferrarelli, "Analysis of LEO, MEO, and GEO global mobile satellite systems in the presence of interference and fading," *IEEE J. Sel. Areas Commun.*, vol. 13, no. 2, pp. 291 –300, Feb. 1995.

[3]P. Noschese, and et al, "ADS-B via Iridium NEXT satellites," Tyrrhenian Int. Workshop on Digital Commun. - Enhanced Surveillance of Aircraft and Vehicles, pp.213-218, 12-14 Sept. 2011

[4]C.-S. Park, and et al, "Interference analysis of geostationary satellite networks in the presence of moving non-geostationary satellites," in *ITCS 2010*, Aug. 2010, pp. 1 –5.

[5]J. M. P. Fortes, and et al "An analytical method for assessing interference in interference environments involving NGSO satellite networks," *Int. J. Sat. Commun.*, vol. 17, no. 6, pp. 399–419, Dec. 1999.

[6]S. K. Sharma, S. Chatzinotas, B. Ottersten, "Exploiting polarization for spectrum sensing in cognitive SatComs", in *proc. 7th Int. ICST Conf. on CROWNCOM*, vol., no., pp.36-41, 18-20 June 2012.

[7]S. K. Sharma, S. Chatzinotas, B. Ottersten, "Spectrum Sensing in Dual Polarized Fading Channels for Cognitive SatComs", in *proc. IEEE Globecom* 2012, vol., no., pp. 3426-3431, 3-7 Dec. 2012.

[8]S. Kandeepan, and et al, "Cognitive Satellite Terrestrial Radios", in *IEEE Globecom*, vol., no., pp. 1-6, 6-10 Dec. 2010.

[9]Y. H. Yun and J. H. Cho, "An orthogonal cognitive radio for a satellite communication link", *IEEE 20th Int. Symp. on PIMRC*, pp. 3154-3158, 2009.

[10]S. K. Sharma, S. Chatzinotas and B. Ottersten, "Cognitive Radio techniques for Satellite Communication Systems", to appear in proc. VTC-fall 2013, Las Vegas, CA, Sept. 2013.

[11]S. Chatzinotas, S. K. Sharma, and B. Ottersten, "Frequency packing for interference alignment-based cognitive dual satellite systems", to appear in proc. VTC-fall 2013, Las Vegas, CA, Sept. 2013.

[12]S. K. Sharma, S. Chatzinotas, and B. Ottersten, "Spatial Filtering for Underlay Cognitive SatComs", to appear in proc. 5th Int. Conf. PSATS, Toulouse, France, June 2013.

[13]S. K. Sharma, S. Chatzinotas, and B. Ottersten, "Interference Alignment for Spectral Coexistence of Heterogeneous Networks", EURASIP J. Wireless Commun. and Networking, vol. 2013:46, 2013.

[14]S. K. Sharma, S. Chatzinotas, and B. Ottersten, "Transmit Beamforming for Spectral Coexistence of Satellite and Terrestrial Networks", in proc. 8th Int. Conf. CROWNCOM, Washington, USA, July 2013.

[15]S. K. Sharma, S. Chatzinotas, and B. Ottersten, "Cognitive Beamhopping for Spectral Coexistence of Multibeam Satellites", to appear in proc. Future Network Mobile Summit 2013, Lesbon, Portugal, July 2013.

[16]A. Reed and M. Posen, "Interference in the fixed satellite service bands between the feeder-links of networks using nongeostationary satellites and network using geostationary satellites," in *3rd European Conf, on Satellite Commun.*, Nov 1993, pp. 251 –256.

[17]H. Kobayashi, H. Shinonaga, N. Araki, and Y. Ito, "Study on interference between non-GSO MSS gateway station and GSO FSS earth station under reverse band operation," pp. 282 –289 vol.1, may 1995.

[18]TSL, "Introduction to visualyse systems," online, 1996, Transfinite Systems Ltd., url: http://www.transfinite.com/content/software1.html.

[19]F. Ghazvinian, and M. A. Sturza, “Co-directional Ka-band frequency sharing between non-GSO satellite networks and GSO satellite networks,” online, url: http://www.3csysco.com/Pubs/Co-Directional.

[20]C.-S. Park, C.-G. Kang, Y.-S. Choi, and C.-H. Oh, “Interference analysis of geostationary satellite networks in the presence of moving non-geostationary satellites,” in *2nd Int. Conf. ITCS, 2010* , Aug. 2010, pp. 1 –5.

[21]TSL, “The O3B Network and EPFD”, Transfinite systems, White paper, available online: http://www.transfinite.com/papers/O3b.pdf.

[22]O3b, “Our Technology”, O3b Networks, available online: http://www.o3bnetworks.com/o3b-advantage/our-technology.

[23]S. K. Sharma, S. Chatzinotas, and B. Ottersten, “Inline Interference Mitigation Techniques for Spectral Co-existence of GEO and NGEO Satellites”, to be submitted to Int. J. Satellite Commun. and Networking, under preparation.