Interference Analysis Due to Spot Beams Drift in Integrated Satellite-Terrestrial Networks

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Abstract. Integrated satellite-terrestrial networks can improve both the service coverage and spectral efficiency in spot-beam-based mobile satellite service system (MSS). In an integrated satellite-terrestrial network, MSS frequency is reused in both satellite spot beams and complementary ground component (CGC). Due to reuse of frequency, co-channel interference is present in both intra-component (between CGCs) and inter-component (between satellite spot beam and CGC). Without spot beams drift, these interferences have tolerable levels for acceptable performance in voice and/or data communication. However, in practice, especially the inter component interference will start to grow if the spot beams drift from their nominal positions due to pointing error of spot beams. In this paper, we study the interference from the satellite component to the ground component when the drifted spot beams start to interfere with CGCs reusing the same frequency. The interference levels depend on the drift magnitude, drift angle, and also the protection ring size utilized by the ground component. Simulation results are provided for different values of these parameters and giving new insight into the effects of spot beam drifting in an integrated satellite-terrestrial network.

1 Introduction

Recently, the International Telecommunication Union (ITU) has defined the concept of an integrated mobile satellite service (MSS) system [2,3,4,6]. In this concept both satellite based network (SBN) and complementary terrestrial based network (CTN) are interconnected and controlled by satellite resource and network management system [3].

CGC is ground-based component which interact directly to the core network [6]. CGC is also called by CGC type 1. Type 1 is L3 type of relay where from user equipment (UE) point of view is considered as a cell of its own. Different types of CGCs are discussed in [6]. In this paper (here after), we will use the terms CGC and terrestrial cell interchangeably. In both of these entities MSS band is used to provide services seamlessly directly by satellite or via CGC. The main purpose of building such integrated satellite-terrestrial network is to improve satellite service coverage in areas where the satellite communications suffer from high blocking factor. On the other hand, spectral efficiency is increased by reusing frequency in both SBN and CTN [3].

However, having benefits of increasing spectral efficiency and improving service coverage using integrated satellite-terrestrial system, therein remain significant challenges to be resolved to foresee the successful deployment of integrated satellite-terrestrial system. One of the major challenges is to avoid or mitigate intra- and

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inter-component co-channel interference caused by using same frequency in integrated terrestrial-satellite system. Intra-component interference is generated within terrestrial cells. On the other hand, inter-component interference is generated between terrestrial cells and satellite spot beams. In ideal situation these interferences have tolerable levels for acceptable performance in voice and/or data communication. But in practice the spot beams are not fixed to the Earth surface. There are various types of natural perturbing forces which will cause the GEO (Geostationary Earth Orbit) satellite to drift out from its original path and assigned position towards so-called inclined orbit [5]. Hence, antenna system will not be anymore aimed properly with the right pointing of its spot beams projection towards the Earth surface. As a result, inter component co-channel interference will start to grow if the spot beams drift from their nominal positions.

Very few papers have discussed the co-channel interference issues in integrated satellite-terrestrial systems [1,8]. In [1], a model of an integrated mobile network composed of a multiple spot beams satellite and terrestrial base stations (BSs) is presented. This model is then used for analyzing uplink co-channel interference issues in integrated satellite and terrestrial mobile systems. Moreover, analysis of interference issues in integrated satellite and terrestrial mobile system have been done by assuming that satellite spot beam is completely fixed relative to the Earth surface. In [8], experimental based study has been conducted to investigate the interference issues in integrated satellite-terrestrial system. In both [1] and [8], drift of spot beams are assumed to be maintained fixed. However, in inter-component interference analysis the knowledge of drifting of spot beam is essential. Depending on the pointing accuracy of the spot beams, the position of the satellite spot beam pattern compared to the terrestrial cells can vary within a range of several of kilometers. Hence, performance analysis of integrated satellite-terrestrial system under the influence of spot beam drift is an important issue to study.

In this paper, we will analyze both intra component and inter component downlink interference issues for integrated satellite-terrestrial system when the multiple satellite spot beams drift. In our usage scenario, multiple satellite spot beams cover a large geographic area which could include a large number terrestrial cells. Thus, when the adjacent spot beams drift, satellite downlink interference could impinge on a large group of co-channel terrestrial cells within the scope of satellite spot beams drift. The interference level depends on the drift magnitude, drift angle and also on protection ring size around the spot beam.

2 System Model

For co-existence assessment, in this study, GEO (Geostationary Earth Orbit) multi-beam satellite is considered as space component and CGC as ground component. Geographic target area is considered as rectangular area. The target area is then sub-divided into many service areas where services will be provided to users. For the sake of simplicity we will consider only one service area which resides in the middle of the target area. A cluster of spot beams of integrated satellite-terrestrial system and its overlaid CGC cells is shown in Fig. 1. The coverage of the spot beam is modeled by two geometrical shapes. Nominal coverage is bounded by hexagonal shape and the outer coverage of the spot beam is bounded by circular shape. This circular shape ring is called protection ring. Protection ring is basically part of spot beam coverage. The purpose of

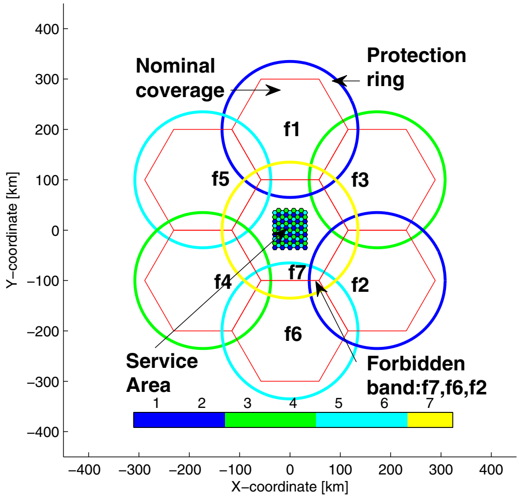

Fig. 1. A cluster of spot beams (7 spot beams in one cluster)

creating protection ring around each satellite spot beam is for not emitting or receiving too much interference to/from adjacent spot beams and terrestrial cells. Inside each protection ring the frequency used by the corresponding spot beam is not allowed to be reused by the CGC. An example of forbidden channels within the cross section of spot beams is also shown in Fig. 1. Very large size of protection ring will reduce inter-component interference. However, it will lead to a reduced set of MSS channels left available to the CGC [1]. Transmission power for each CGC cell is same. Frequency allocation in each spot beam and terrestrial cells for a specific service area is done in such a way that they are orthogonal. The shape of terrestrial cells is also considered as hexagonal. Cell size varies depending on the environment such as rural and urban case. Nominal positions of all spot beams in ideal situation (without drift) is shown in Fig. 1. Users distribution in every terrestrial cell is assumed to be uniformly distributed. There are several ways to plan the reuse pattern for terrestrial networks. In this paper, we will use frequency reuse factor 3 for terrestrial cells and 7 for satellite spot beams. If the given MSS bandwidth is 50 MHz then for a particular spot beam and its overlaid terrestrial cells, MSS band will be divided equally into seven sub bands. One sub band

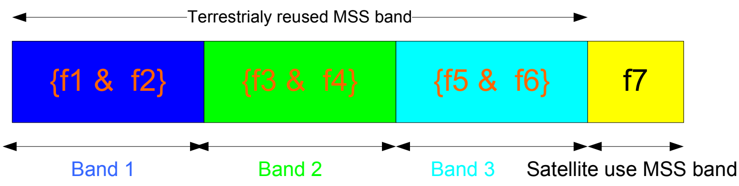

Fig. 2. MSS band allocation in satellite spot beam and terrestrial cells (14.2 MHz/CGC and 7.1 MHz/spot beam)

will be allocated to satellite which is equivalent to 7.1 MHz and the rest will be used for terrestrial cells. In this case, each sub band will be equivalent to 7.1 MHz. However, due to our assumption of frequency reuse factor 3 for terrestrial cells, allocated six sub bands will be combined to form three bands. Hence, each band of terrestrial cell will be basically combination of two sub bands which is equivalent to 14.2 MHz. Band allocation to a particular terrestrial cell is shown in Fig. 2 where blue, green and cyan are represented as terrestrially reused MSS band and yellow is represented as satellite spot beam used band (here f_7). Moreover, in Fig. 2, blue color band is termed as band 1 and is composed of two sub bands $\{f_1, f_2\}$. Similarly, band 2 (green) and band 3 (cyan) are composed of $\{f_3, f_4\}$ and $\{f_5, f_6\}$ respectively. Frequency plan is carried out in C band either between 3.4 GHz and 3.55 GHz or between 3.6 GHz and 3.75 GHz.

3 Drift of Spot Beams

The pointing error of drifted spot beam may vary depending on the orbit chosen for satellite. The statistics of the drift trajectory can be obtained via measurement. However, in this paper, we use a simple pointing error model to analyze the interference issues under the influence of multi spot beams drift. In modeling pointing error of drifted spot beam, we characterize it by two key parameters: drift angle and drift magnitude. Drift angle will define the direction of spot beam drift. On the other hand, drift magnitude defines length of trajectory path towards a certain direction of spot beam drift. Unless otherwise specified drift angles are uniformly distributed. However, in this work most results assumed given fixed drift angles.

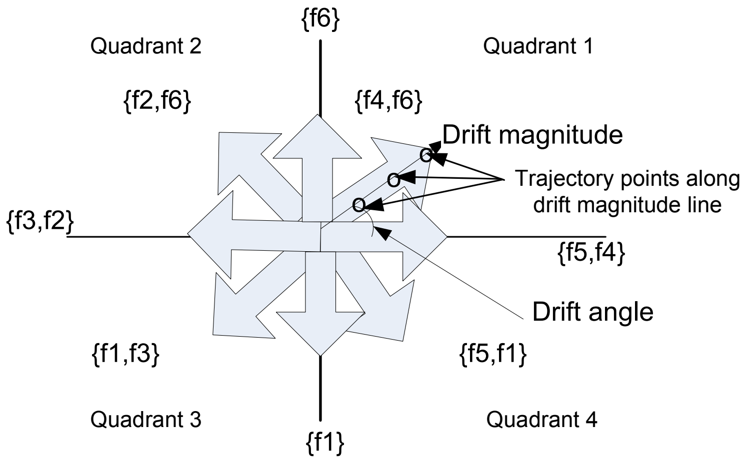

Fig. 3. Orientation of inclined and non-inclined drift angles of spot beams

According to the orientation of drift angle we can characterize it into two types of pattern of drift angle: non-inclined and inclined. The details of two different orientation of drift angles are given below:

In inclined orientation, drift angle of spot beams will be inclined to any one of the four quadrants as shown in Fig. 3. For example if the drift angle resides in quadrant 1 then two spot beams from the opposite quadrant will interfere the cells, in this case $\{f_4, f_6\}$ will be responsible spot beams to interfere the target service area. Similarly if the drift resides in quadrant 2, quadrant 3 and quadrant 4 then the set of spot beams such as $\{f_2, f_6\}$, $\{f_1, f_3\}$, $\{f_1, f_5\}$ will be responsible to interfere with the service area respectively.

In non-inclined orientation of drift angle, spot beams will drift either horizontally or vertically. Moreover if it drifts horizontally it can drift either left side or right side from its nominal positions. In this case $\{f_5, f_4\}$ and $\{f_3, f_2\}$ will be responsible sets of spot beams to interfere with the service area. On the other hand, if it moves vertically it can drift either top or downwards from its nominal position. In this case, only one spot beam either $\{f_1\}$ or $\{f_6\}$ will interfere with the service area. However, all of the above considerations are for moderate realistic protection ring sizes.

4 Channel Model

The path loss model used in this work is [7]:

$$A = A_0 + 10\gamma \log\left(\frac{d}{d_0}\right) \tag{1}$$

where A_0 is the intercept attenuation at a distance d_0 from the CGC, γ is the pathloss exponent. d_0 and d are the reference distance and distance between user and CGC. The signal-to-interference ratio (SIR) in terrestrial system depends on many factors, including the cell layout, cell size, reuse distance, and propagation. SIR for a non-collided user is

$$SIR = \frac{P_{desired}}{\sum P_{interference}} \tag{2}$$

where $P_{desired}$ is the signal strength from the desired CGC and $P_{interference}$ is the interference signal strengths from neighboring co-channel CGCs. The SIR for a collided (victim) user contains both the co-channel interference and inter-component interference from the overlapping drifted satellite spot beam and is written as

$$SIR = \frac{P_{desired}}{\sum P_{interference} + \sum P_{satellite}} \tag{3}$$

where $P_{satellite}$ is the summation of satellite interference powers experienced by the desired user from the co-channel drifted spot beams.

5 Simulation Results

In this section interference of integrated satellite-terrestrial has been evaluated using pointing error model presented in Section III and the parameters presented in Table 1. In our simulation, we consider geographic area of $70 \times 70\ \mathrm{km}^2$ reflecting the size of a

Table 1. Simulation Model Parameters

Simulation Parameters	Value
Service Area	$70 \times 70\,\text{km}^2$
Protection ring size	135 km
Frequency reuse factor for cellular	3
Frequency reuse factor for satellite	7
CGC cell radius	5 km
Drift angle	Uniform or $(0^o, 45^o, 90^o)$
Number of users per cell (CGC)	100
Path loss exponent (α)	3.8
A_0	105.45 dB
Reference distance (d_0)	200 m
Satellite interference power	-104 dBm
Transmission power (CGC)	43 dBm
Minimum receiver sensitivity (CGC)	6.4 dB

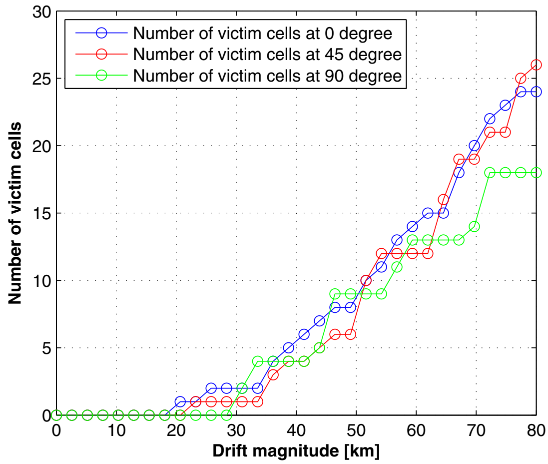

Fig. 4. Number of victim cells due to drift of spot beam vs. drift magnitude

service area of a city. As performance metrics, we use the number of victim cells and received SIR level.

Fig. 4 shows the number of victim cells with respect to the different length of drift magnitude of the spot beam(s). The studied drift angles were 0^0, 45^o and 90^o. It can be seen that with 135 km protection ring radius and for all chosen drift angles there are no victim terrestrial cells up to 19 km of drift magnitude of spot beam. However, number of victim cells will start to grow after 20 km. It is also seen that when drifted spot beam moves from one trajectory point to another trajectory point, the pattern of victim cells plot also changes. Sometimes it is flat along multiple consecutive trajectory points and sometimes it jumps from present to next trajectory point. Flatness of the plot shows that the number of victim cells will remain same even though spot beam moves forward

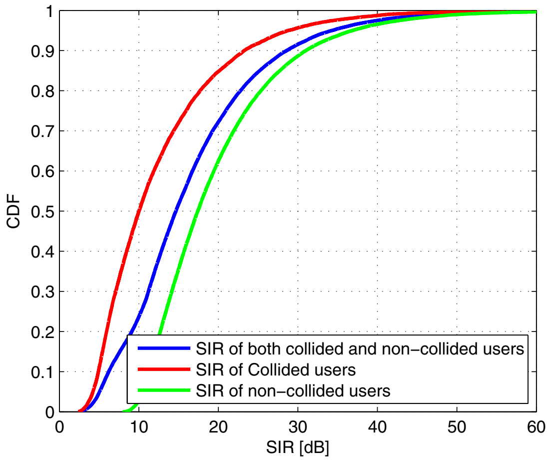

Fig. 5. Received SIR level with and without spot beams drift

and overlapped terrestrial cells. In this case, the frequency of overlapped terrestrial cells is orthogonal to the frequency of the drifted spot beam. On the other hand, increment of number of victim cells will occur when there is co-channel interference between terrestrial cells and spot beam. Figure 4 also shows the impact of influence of single or multiple spot beams on the service area. For example, at 90^o drift angle only one spot beam $\{f_1\}$ will be interfere with the co-channel terrestrial cells. On the other hand, when the drift angles are 0^o and 45^o, two spot beams $\{f_4, f_5\}$ and $\{f_4, f_6\}$ respectively will interfere with the terrestrial cells. Therefore, specially at the higher drift magnitude, number of victim cells increase more when two spot beams overlap the terrestrial cells then by one spot beam.

Fig. 5 shows the three sets of CDF plots of received SIR levels. Green CDF plot shows the SIR level when there is no drift of spot beams. Blue CDF plot shows the collection of SIR level for collided users as well as for non-collided users. In practice, when spot beams drift only co-channel terrestrial cells will be victim and others terrestrial cells will be free from satellite interference even though overlap by drifted spot beams. Finally, red curve CDF plot shows the SIR level only for victim users. It is clearly seen that there is a impact of satellite interference on the performance of integrated satellite-terrestrial system. For example, if the minimum required SIR level is 6.4 dB, then it is seen that with around 24 percent probability the collided users will have less than 6.4 dB. Ultimately the users those who have less than 6.4 dB SIR level in the victim cells will go to outage.

6 Conclusions

In this paper, we have studied downlink interference issues due to pointing errors of spot beam in an integrated satellite terrestrial network. Pointing errors of spot beams characterized by two key parameters: drift magnitude, drift angle. Apart from pointing errors parameters other key parameters associate to model integrated satellite-terrestrial system such as protection ring size, frequency reuse factor of both satellite spot beam and terrestrial cell are also taken into account. Finally simulation has been performed to evaluate the performance of such network under the influence of spot beam by taking into account performance metrics such as victim cells, and SIR. Simulation results helped to understand that there exist significant inter-component interference due to drift of spot beam. Moreover, simulation results reveal that as the drift magnitude of the spot beam increases the performance of integrated satellite-terrestrial system decreases. Hence, it is worthwhile to further investigate the inter-component interference issues by taking into account more detailed physical layer model, different network load and simulate for various application scenarios.

In summary, we can conclude that as the pointing errors of spot beam are inevitable it is also worthwhile to study and find the possible solutions to mitigate and/or avoid these interferences for future development as well as deployment of integrated satellite-terrestrial system.

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