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Compatibility of integrated satellite systems with another satellite system operating in adjacent beam

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Abstract—This paper addresses the analysis of the interference between complementary ground component (CGC) base station and mobile earth station (MES). In the frequency sharing scenario between CGC base station and MES, the interference from the adjacent beams must be considered. In this paper, we estimated the interference to MES of an integrated satellite system and the result is presented as the carrier to interference ratio(*C/I*) with respect to the number of CGC base station in the adjacent beam and the ratio of satellite beam center radius to the total beam radius (R_1/R). By using these results, we can determine the minimum separation distance between the CGC base stations of adjacent beam and MES for compatibility. This result can be applied to the CGC base station of an integrated satellite system for the effective frequency sharing.

Keywords— Integrated Satellite System, Interference, Frequency Reuse pattern, CGC base station, MES, Frequency sharing.

I. Introduction

As the number usable satellite systems in space increases, the frequency co-existences between the satellite system and other radio service is being increased rapidly in the time and space domain. To meet demands from various countries for frequency efficiency, various frequency reuse scheme of integrated satellite system are being developed. In the integrated satellite system, it is essential to reuse frequencies between the satellite and CGC base station under tolerable interference levels because satellite bandwidth is limited in resources. The proposed system is capable of supporting frequency efficiency. Performance on the proposed satellite reuse pattern in the CGC base station of an integrated satellite system is analyzed in term of interference level[1].The paper aims at analyzing co-frequency interference for integrated satellite system. In this paper, the methods to mitigate co-frequency interference will be presented and discussed. Section Ⅱ is the detailed description of the multi-beam satellite system frequency reuse pattern and simplified interference scenario. Section Ⅲ describes the numerical computation procedure of the statistics of the total interference produced by CGC base station. The results of computation in Section Ⅳ. This result can be used to define the minimum separation distance for protection of MES from the total interference by the adjacent beam CGC base stations. Conclusions are summarized in Section Ⅴ.

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II. Interference Model

In this section we describe the frequency reuse pattern and interference scenarios which are used to analyze in term of interference level.

A. Frequency reuse pattern

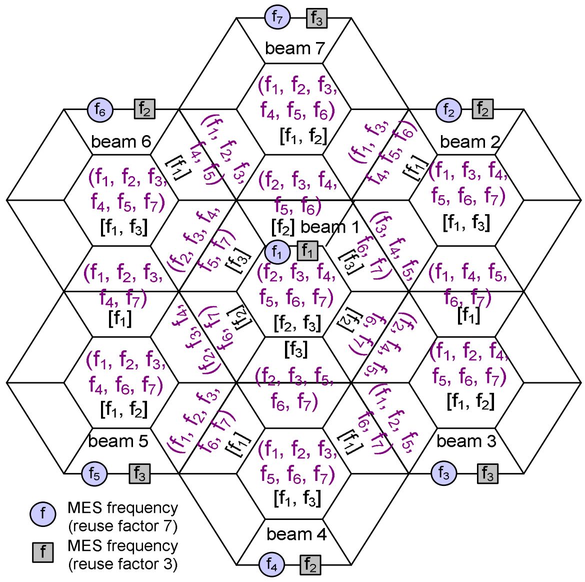

Fig. 1 Multi-beam satellite system frequency reuse pattern
((·)= reuse factor 7 and [·]=reuse factor3)

We introduce a frequency reuse scenario of integrated satellite system with reuse factor 7 and 3 in fig. 1. Multi-beam satellite communicates with MES using frequency from f1 to f7 (reuse factor 7) and from f1 to f3 (reuse factor 3) in each satellite beam. Each beam is sectioned into seven regions and all the available reuse frequencies are divided in each beam. CGC base station uses the frequency which is not allocated for MES. Frequency group in satellite cell means the reused frequency in CGC base station of multi-beam satellite system.

It is noted that the CGC base station can reuse satellite resources when only one of the seven frequencies is allocated for the MES. When the MES is in area of beam 1, the CGC base station deployed at the center of beam 1 can reuse the satellite resources of the frequency from f2 to f7 with no intra-beam interference and negligible co-cell interference to the MES. The CGC base station operated at the edge of beam 1 can induce the interference to the MES because adjacent beam. The CGC base station deployed at the center of each beam reuses frequency except the allocated frequency for the MES in the targeted beam edge, while the CGC base station at the edge of each beam reuses the frequency except the frequency allocated for the MES in the targeted and adjacent beam edges.

B. Simplified interference scenario

The CGC base station transmissions have the potential to cause interference to MES operating f1 in the adjacent geographical region. In the figure 2, beam 6 is sectioned into seven regions from A to F. The regions are defined in order to calculate interference to MES in beam 1. The integrated satellite system consists of one thousand of random CGC base stations and one victim MES within one satellite beam. The f1 frequency is shared with CGC base station and interference signal from CGC base station is received by MES.

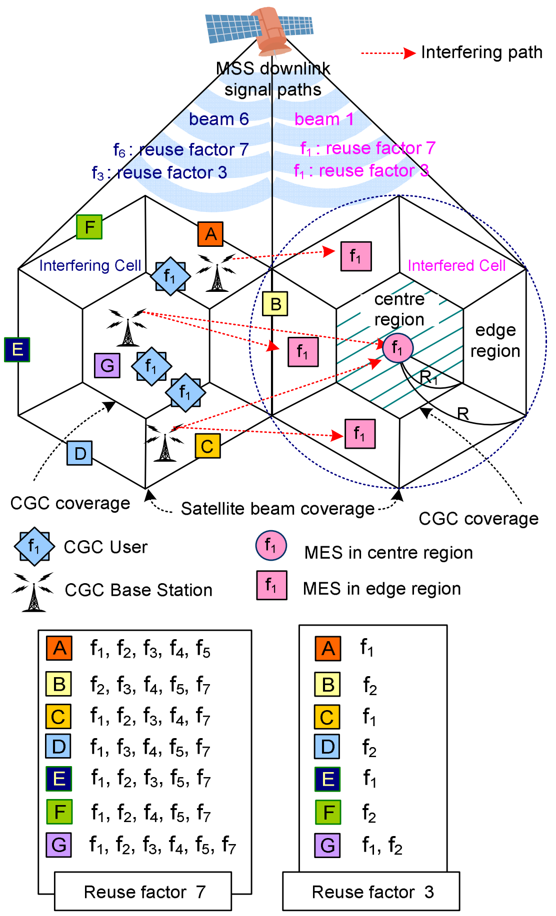

Fig. 2 Simplified Interference scenario (Between beam 1 and beam 6)

B region is not affected by the interference because it does not use frequency f1. Additionally, we can ignore the interference from D, E, F regions to MES because these regions are far from beam1. The calculation of exact position of the CGC base station is important because the calculated position is used for calculation of distance from victim MES and it can affects the results seriously.

III. CALCULATION MODEL

We assume some parameters for integrated satellite system as shown in Table Ⅰ. And, we assume satellite beam cell radius as 2000km and 1000 CGC base stations in each satellite cell of the integrated MSS system. The CGC base station is considered as random distribution in per unit. A basic criterion for frequency sharing is also defined Table Ⅰ. We use the antenna radiation pattern in Recommendation F.699 for CGC base station's antenna [3].

TABLE I
Relevant symbols and parameters for interference calculation

Parameters	Symbol	value
e.i.r.p of satellite	$e.i.r.p_{SATELLITE}$	37 dBw
e.i.r.p of CGC	$e.i.r.p_{CGC}$	25 dBw
Frequency	f	2GHz
MES antenna gain for wanted carrier	G_{MES}	2 dB
MES antenna gain for interferer	G_{I_MES}	2 dB
Bandwidth of the satellite MES	B_{MES}	40 kHz
Bandwidth of the CGC	B_{CGC}	5 MHz
C/I protection requirement	$C/Ireq$	20dB

From the figure 2, we can see that the interference from the adjacent beams is mainly contributed from the CGC base station in the A, C and G region of beam 6. Probability for CGC base station to be located in A, C and G using frequency f1 is expressed by (1), where R1 is satellite beam center radius and R is total satellite beam radius.

$$P = \begin{cases} f_A = f_C = \frac{1}{6}\left(1 - \frac{R_1^2}{R^2}\right) \\ f_G = \frac{R_1^2}{2R^2} \end{cases} \quad (1)$$

The simulation results show the total *C/I* from all CGC base station at MES. We can calculate the total *C/I* (carrier to interference ratio) from the CGC base station to the MES using (2). The *C/I* is defined as the rate of total power within the digital carrier and the total interference power which are produced by all the transmit CGC base station. A basic criterion for frequency sharing is also defined in Table Ⅰ.

$$C/I_k = e.i.r.p_{SATELLITE} - e.i.r.p_{CGC} - L_W + L_{I\_CGC} + G_{MES} - G_{I\_MES} - 10\log(B_{MES}/B_{CGC})\ [dB] \quad (2)$$

Where, k is the number of transmit CGC base station, L_W is the path loss between the wanted satellite and the wanted MES in dB and L_{I_CGC} is the path loss between the CGC base station and the wanted MES in dB. The path loss is a function of the distance. In order to perform computation using (2), the location information of the CGC base stations is needed as well as a worst-case assumption on the maximum number of CGC base stations operating at the same time in the MES. The CGC base station carrier bandwidth is larger than the MES carrier bandwidth so we have to consider bandwidth factor ($10\log(B_{MES}/B_{CGC})$).

To determine the minimum separation distance, we have to calculate the required loss L_{I_CGC} from C/I_{req} using (3). The minimum separation distance is calculated using (4)

$$L_{I\_CGC} \geq (C/I)_{req} - e.i.r.p_{SATELLITE} + e.i.r.p_{CGC} + L_W - G_{MES} + G_{I\_MES} + 10\log(B_{MES}/B_{CGC})\ [dB] \quad (3)$$

$$L_{I\_CGC} = 32.44 + 20\log(f_{MHz}) + 20\log(d_{km})\ [dB] \quad (4)$$

It is possible to determine the minimum required distance between the CGC base station and the MES. Where, the unit of frequency is MHz and minimum distance is km.

IV. Results of Studies

In this section, co-frequency interference between multi-beam satellite and CGC base station is evaluated. Figure 3 shows *C/I* at the MES in various R1/R based on the reuse factor with 3 and 7 and MES region under free space propagation condition. MES region means that the region where the MES is located. The MES were distributed randomly into MES region. From the figure 3, we can see that the case of reuse factor with 7 and MES in center region has better *C/I*. The results in case of reuse factor 7 shows better performance than those of reuse factor 3 in term of both MES in edge region and center region. The results indicate that *C/I* in the edge region decreases more rapidly than center region.

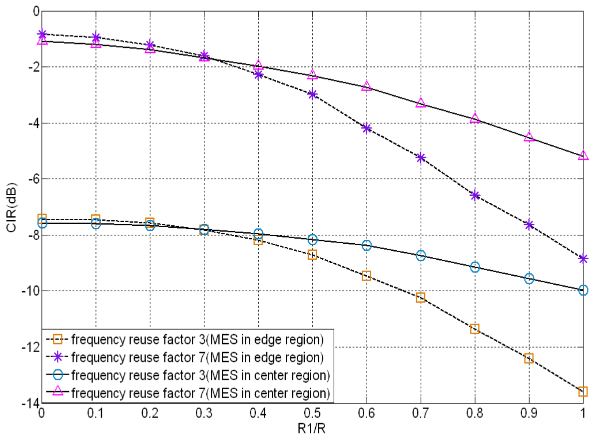

Fig. 3 Simulation result of C/I at the MES

We can calculate the minimum separation distance in order for the interference not to exceed the acceptable level. To determine the minimum separation distance, we derive required loss L_{I_CGC} which meets C/I_{req} for each case of reuse factor 7 and 3. When C/I_{req} is 20dB, the separation distance is calculated along R1/R. Figure 4 shows minimum separation distance between all the transmit CGC base stations and one MES according to the R1/R. The calculated minimum separation distances were determined to protect MES receivers from a multiple number of CGC base stations. The separation distance is much longer when the R1 is bigger for every occasion. When R1/R is 0.5, the minimum separation distance is about 1230km (reuse factor 3 and MES in center region), 1190km (reuse factor 3 and MES in edge region), 620km (reuse factor 7 and MES in center region) and 580km (reuse factor 7 and MES in edge region) respectively.

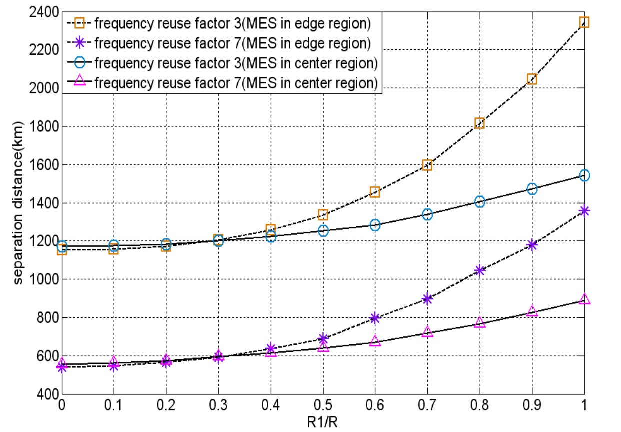

Fig. 4 Minimum separation distance between multiple CGC base stations to MES

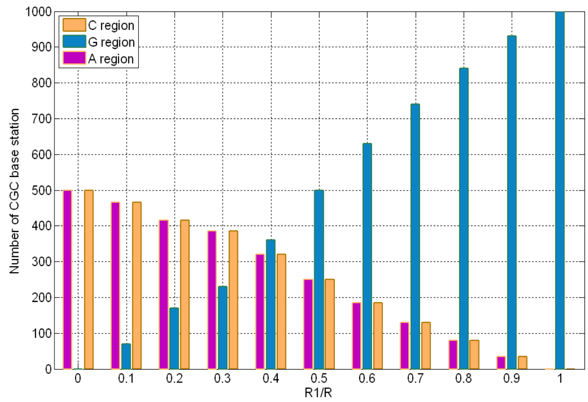

Fig. 5 Number of CGC base station with each region

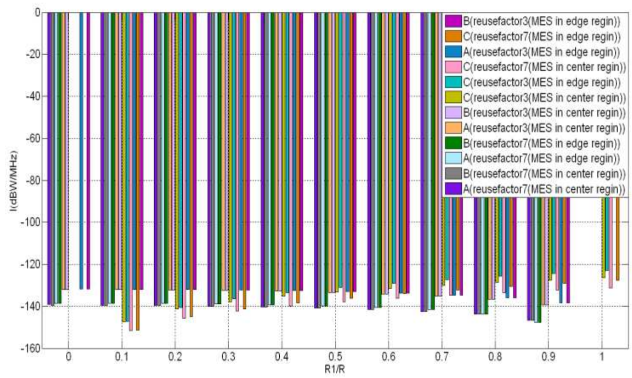

Fig. 6 Simulated Interference level with region in beam 6

Figure 5 shows the number of CGC base station according to R1/R for the three regions in beam 6. Figure 6 shows calculation results of aggregated interference level at each region in beam 6. The number of CGC base station is always subject to variation according to R1/R at each region because the CGC base station is uniformly distributed per unit area. In figure 5 and 6, the Interference level at each region is subject to the number of CGC base station. Aggregation interference level from beam 6 to MES in beam 1 is not much varied on R1/R. If the number of CGC base stations demand is increase in some region, the system performance is tenable by the number of CGC base station in other region. Figure 7 shows the results of the probability distribution obtained from reuse factor 7 and 3. The results are expressed in terms of the cumulative distribution function (CDF). In figure 7, the maximum interference level calculated for reuse factor 7 is -151(dBW/MHz) and -150 (dBW/MHz) for reuse factor 3. These results can be applied to the system design with proper communication performance taking into account the reuse factor and number of CGC base station.

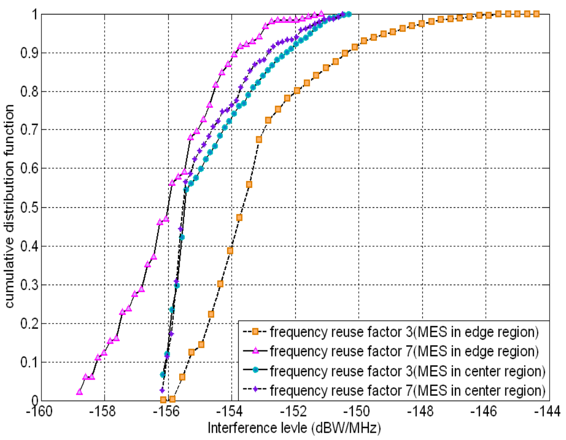

Fig. 7 cumulative distribution of received interference

V. Conclusion

In this paper, we concentrated in the evaluation of the interference and the required separation distance between multi CGC base station and a victim MES. We estimated the interference to MES of an integrated satellite system and the result is presented as the carrier to interference ratio(C/I) with various parameters such as the number of CGC base station in the adjacent beam and the ratio of satellite beam center radius to the total beam radius (R_1/R). The minimum separation distance between CGC base station and the MES is calculated at each R1/R. The calculated minimum separation distances were determined to protect MES receivers from a multiple number of CGC base stations. The results could be used for planning an integrated satellite system deployment under tolerable interference.

Acknowledgment

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