Interference scenarios and methodologies between a terrestrial mobile service (MS) system and mobile-satellite service (MSS) system in a co-channel environment are established. Taking into account a practical deployment situation for both systems, we perform computational simulation of interference in terms of carrier-to-interference ratio (C/I) and interference-to-noise ratio (I/N) to evaluate the cofrequency interference from an MS system into an MSS system, and from an MSS system into an MS system, respectively. The methodology and results can be used as a guide when planning the deployment of MSS and MS systems with no unacceptable interference impact between them.

Keywords: Mobile-satellite service, mobile service, interference, carrier-to-interference ratio (C/I), interference-to-noise ratio (I/N).

I. Introduction

Interest in mobile-satellite service (MSS) is increasing worldwide, and development toward multimedia, broadband, and integrated systems has been made to provide various communications services to land, mobile, maritime, and aeronautical users [1]. MSS systems now operate in a variety of frequency bands, depending on the type of services offered. Originally, the International Telecommunication Union (ITU) allocated spectrum to MSS in the L-/S-bands. As the range of systems and services on offer has increased, the demand for bandwidth has resulted in a greater range of operating frequencies, from VHF up to the Ka-band and, eventually, even into the V-band [2].

Mobile service (MS) has been taking an important role in establishing the foundation of an advanced information society. It enables users to communicate with anyone, anytime, and anywhere. MS systems have evolved to meet user demands fully; therefore, the demand for more frequency spectrum has been increasing. Considering that international mobile telecommunication (IMT) systems can provide various telecommunications services over a wide range of user densities and geographic coverage areas [3], the World Radiocommunication Conference (WRC) held in 2007 organized by ITU has further identified some frequency bands based on technical studies such as those in [4]. For several frequency bands, MSS and MS are allocated in the same bands on a coprimary basis.

Under the circumstances, when we plan to deploy an MSS or MS system, it is very important to conduct a timely investigation into any possibility that one service in the same frequency band would cause unacceptable interference to the other.

In this paper, we present interference scenarios and a
methodology to evaluate cofrequency interference between an MSS system using a geostationary satellite and a terrestrial MS system. We also show the results of a computational simulation using the methodology, also taking into account practical deployment environments for both systems.

II. Interference Scenarios and Methodology

1. Interference from MS System into MSS System

Figure 1 shows an interference scenario from an MS system into an MSS uplink. We assume that the MSS system adopts a frequency reuse scheme because recent MSS systems provide up to hundreds of spot beams with frequency reuse, as in the Thuraya system which utilizes up to 300 spot beams with 30 times frequency reuse. For interference evaluation in this situation, we consider the interference impact by a mobile earth station (MES) in other cofrequency cells as well as the interference impact by the transmitters of user equipment (UE) and base station (BS) on the MS. Further, we calculate the aggregate interference by moving the MS coverage from the center of the MSS coverage linearly in longitude in order to obtain the possible separation distance to meet the interference criteria.

We can calculate the apparent increase in equivalent noise temperature of the satellite link subject to interfering emissions as in [5] as

$$\Delta T = \frac{1}{k} \left( \sum_{m=1}^{n_{mes}} i_{m} + \sum_{n=1}^{n_{ue}} i_{n} \right)$$

$$= \sum_{m=1}^{n_{mes}} p_{m} g_{1,m} g_{2,m} + \sum_{n=1}^{n_{ue}} p_{n} g_{3,n} g_{4,n},$$

where $n_{mes}$ is the number of MESs in other cofrequency cells; $i_{m}$ is the interference power density due to the $m$-th MES in other cofrequency cells; $n_{ue}$ is the number of UE or BS of the MS; $i_{n}$ is the interference power density due to the $n$-th UE or BS of the MS; $p_{m}$ denotes the transmission power density from the $m$-th MES in another cofrequency cell; $g_{1,m}$ is the gain of the $m$-th transmitting MES in the direction of a space station (SS) receiver; $g_{2,m}$ is the gain of an SS in the direction of the $m$-th transmitting MES; $l_{m}$ is the free-space transmission loss between the $m$-th MES and the SS; $p_{n}$ is the transmission power density from the $n$-th UE or BS of the MS; $g_{3,n}$ is the gain of the $n$-th transmitting UE or BS of the MS in the direction of the SS receiver; $g_{4,n}$ is the gain of a SS in the direction of the $n$-th transmitting UE or BS; $l_{n}$ is the free-space transmission loss between the SS and the $n$-th UE or BS of the MS; and $k$ is a Boltzmann’s constant ($1.38 \times 10^{-23}$ J/K).

For the interference evaluation, we use the percentage increase in an equivalent satellite link noise temperature, $\Delta T/T$, comparing it to a threshold value of 6% [6]. If $\Delta T/T$ is greater than or equal to the threshold value, we need to make detailed calculations in terms of carrier-to-interference ratio (C/I) by dividing the received carrier power at the SS by the interference power given in (1).

Figure 2 shows an interference scenario from an MS system into an MSS downlink. Interference from the MS system into the MSS downlink can be evaluated in a similar way as in the case of the MSS uplink previously described, by replacing some terms for the MES in (1) with those for the multi-beam SS.

2. Interference from MSS System into MS System

Figure 3 shows the interference evaluation methodology from the MSS downlink into the MS system. For interference evaluation in this situation, we calculate the aggregate
interference from all cofrequency transmitting beams of the SS into a UE and BS for the MS. Further, we calculate the aggregate interference by moving the MS coverage from the center of the MSS coverage linearly in longitude for the same purpose as previously described.

We can calculate the interference with a UE or BS for the MS caused by a single beam of SS for the MSS as in [7] as

\[ i = \frac{P_{Tx,MSS} \cdot g_{Tx,MSS} \cdot g_{Rx,IMT}}{I_p \cdot I_f} \cdot a_{bw}, \]  

where \( i \) is the interference power on an in-band UE or BS due to the transmitting beam from a space station for an MSS; \( P_{Tx,MSS} \) is the transmit beam power at the antenna input of a space station; \( g_{Tx,MSS} \) is the gain of a beam from a space station in the direction of the interfered receiver of a UE or BS; \( g_{Rx,IMT} \) is the gain of a UE or BS in the direction of the transmitting beam of a space station; \( l_p \) is the propagation loss between the interfering transmitter of a space station and interfered receiver of a UE or BS; \( l_f \) is the feeder loss at the receivers of a UE or BS; and \( a_{bw} \) is the adjustment factor for different bandwidths between a space station and UE or BS. For the case of an in-band narrow band carrier into a wide carrier, \( a_{bw} \) is the number of carriers that each transmit station is transmitting simultaneously.

Using (2) and the multi-beam consideration, we evaluate interference in terms of the ratio of interference power to thermal noise \((I/N)\) given as

\[ \frac{I}{N} = \sum_{\text{for all co-frequency beams}} \frac{i}{N}, \]  

where \( N \) is the thermal noise of the interfered receiver of the UE or BS for the MS in the relevant bandwidth.

Figure 4 shows the interference evaluation methodology from the MSS uplink into the MS system. We can evaluate the interference with the MS system caused by the MSS uplink system in a similar way as the case of the MSS downlink described previously by replacing some terms for the multi-beam SS in (2) and (3) with those for multi-MES users.

### III. Simulation Results

Tables 1 and 2 present the operational system parameters for the MSS and MS systems for simulation, respectively.

For the antenna pattern of the SS, we assumed a symmetrical circular pattern given as in [8] as

\[ G(\phi) = G_{max} \cdot 2^{n+1} (n + 1)! \cdot \left( \frac{J_{n+1}(\phi)}{(\phi)^{n+1}} \right)^{2}, \]

where \( \phi \) is the off-axis angle; \( G_{max} \) is the maximum antenna gain; \( n \) is the circular aperture taper, which determines the beamwidth, sidelobe level, and directivity characteristics; and \( J_{n+1}(\phi) \) is a Bessel function of the first kind of order, \( n+1 \).

#### Table 1. MSS system parameters for simulation [9].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude of satellite</td>
<td>35,786 km</td>
</tr>
<tr>
<td>Number of spot beams</td>
<td>37</td>
</tr>
<tr>
<td>SS Antenna pattern</td>
<td>Eq. (4)</td>
</tr>
<tr>
<td>Max. e.i.r.p.</td>
<td>40 dBw</td>
</tr>
<tr>
<td>MESS Antenna pattern</td>
<td>Rec. ITU-R M.1091</td>
</tr>
<tr>
<td>Max. antenna gain</td>
<td>12 dB</td>
</tr>
<tr>
<td>Transmission power</td>
<td>1 dBW</td>
</tr>
<tr>
<td>Frequency (down-/up-link)</td>
<td>2.185 / 1.995 GHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>200 kHz</td>
</tr>
</tbody>
</table>
Table 2. MS system parameters for simulation [10].

<table>
<thead>
<tr>
<th>BS</th>
<th>Number of cells</th>
<th>37</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cells</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antenna pattern</td>
<td>Rec. ITU-R F.1336</td>
<td></td>
</tr>
<tr>
<td>Max. antenna gain</td>
<td>18 dBi</td>
<td></td>
</tr>
<tr>
<td>Transmission power</td>
<td>10 dBW</td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>30 m</td>
<td></td>
</tr>
<tr>
<td>Thermal noise power of receiver</td>
<td>-139 dB (W/MHz)</td>
<td></td>
</tr>
</tbody>
</table>

| UE                |                |    |
|-------------------|----------------|
| Max. antenna gain | 0 dBi          |
| Transmission power| -13 dBW        |
| Height            | 1.5 m          |
| Thermal noise power of receiver | -135 dB (W/MHz) |
| Bandwidth         | 5 MHz          |

1. Interference from MS System into MSS System

A. Computational Calculation

Figure 5 shows the distribution of the MSS system for simulation. We selected an MSS uplink reference cell, and some other cofrequency cells were then identified according to the frequency reuse factor (FR) of 3.

For the FR of 3, the number of cofrequency cells was 12, and the number of MESs per each cofrequency cell was 33. The carrier-to-noise ratio (C/N) at the SS receiver from an MES in the reference cell is 10.6 dB, and the protection ratio (PR) would then be 17.6 dB taking into account the permissible level of interference in a geostationary network in the MSS [11]. The calculated ΔTi/T at the SS receiver due to only an MES in all cofrequency cells was 557.2%, which is much higher than the interference threshold of 6%. For a detailed examination, the C/I at the SS receiver due to only an MES in all cofrequency cells was calculated. The calculated C/I was 3.15 dB, which does not meet the requirement for the PR of 17.6 dB. The results indicate that MSS with an FR of 3 cannot operate normally due to the internal interference from the MESs in all cofrequency cells.

Figure 6 shows the distribution of the MSS system applying an FR of 9. The number of cofrequency cells was 4 and the
The calculated $\Delta T/T$ at the SS receiver due to only an MES in all cofrequency cells decreased to 9.9%, which is still higher than the interference threshold of 6%. The calculated C/I was 20.64 dB, and it meets the requirement for the PR.

For calculating $\Delta T/T$ and C/I at the SS receiver due to the MS system, also taking into account the internal interference due to the MESs in all cofrequency cells, we assumed an MS cell distribution of FR=1 as shown in Fig. 7.

Figure 8 shows the calculated $\Delta T/T$ at the SS receiver due to the MS system, taking into account the internal interference due to the MESs in all cofrequency cells. The results indicate that $\Delta T/T$ was greater than the interference threshold over all ranges of distance between service coverage centers. The minimum value was 9.91%.

Figure 9 shows the calculated C/I at the SS receiver due to the MS system, taking into account the internal interference due to the MSs in all cofrequency cells. The results indicate that MSS would not experience unacceptable interference due to the MS system in some geographical ranges. Distances of 304.6 km to 328.9 km and greater than 820.4 km would be required to avoid unacceptable interference by the BS. Distances greater than 222.8 km would be required by the UE.

We also investigated the interference impact by an MS system with a larger FR. Figure 10 shows the MS cell distribution (FR=7). The number of cofrequency cells for the MS was decreased to 5.

Figure 11 shows the calculated $\Delta T/T$ at the SS receiver due to the MS system with an FR of 7. The results indicate that...
$\Delta T/T$ is generally less than that in the case of an FR of 1.

Figure 12 shows the calculated C/I at the SS receiver due to the MS system with an FR of 7. The results indicate that the C/I was generally greater than that in the case of an FR of 1, and the range not experiencing unacceptable interference increased. Moreover, the UE would not cause any unacceptable interference. The results demonstrate that if the FRs for MSS and MS systems are 9 and 7, respectively, and the center of MS coverage is located at 246.2 km to 510 km and more than 610 km from the center of MSS coverage, the MSS system can operate without unacceptable interference from the MS system in a cofrequency environment.

For the evaluation of interference from an MS system into MES, we assumed a cell distribution of the MS system with an FR of 7 and an MSS downlink with an FR of 9 as shown in Figs. 10 and 13, respectively. We investigated the interference impact on each MES in three out of four cofrequency cells because of the symmetry. The C/N at the receiver of the MES from SS in the reference cell is 9.2 dB, and the PR would then be 16.2 dB.

We calculated the C/I at the receiver of the MES due to the MS system with an FR of 7 for each position of the MES reference cell. The C/I's at the MES in the cells of positions 1 and 2 met the PR of 16.2 dB. However, for the case of position...
3, some ranges experienced unacceptable interference due to the MS system as shown in Fig. 14.

B. Analysis of Results

For the interference evaluation at an SS of the MSS (uplink), it was found that as the FR for the MS system increases, interference impact on the SS of the MSS by the MS system decreases due to a decrease in the number of MS systems. In addition, there are certain geographical ranges to exclude MS system deployment from the center of the MSS service coverage in order to avoid causing unacceptable interference to the MSS system.

For interference evaluation at an MES of the MSS (downlink), the results according to the change of the value of FR are similar to the case of MSS uplink. Also, it was found that it would be necessary to investigate the interference impact for each position of a cofrequency MSS downlink cell.

2. Interference from MSS System into MS System

A. Computational Calculation

Figure 15 shows the distribution of the MSS downlink with an FR of 3 to evaluate the interference into the BS and UE for an MS with an FR of 1, as shown in Fig. 16.

Figure 17 shows the results of the calculated I/N at the BS and UE receivers for the MS, respectively. We also investigated the interference impact by an MSS system with a larger FR. Figure 18 shows the MSS downlink distribution with an FR of 7. The number of cofrequency cells for the MSS downlink decreased to 5.

We investigated the interference impact on each BS and UE in the four cofrequency cells as shown in Fig. 19. We calculated the I/N at the BS and UE receivers for the MS in each selected position and found that the interference impact due to the SS with an FR of 7, which is larger than 3, would definitely decrease and would meet the interference criterion of −10 dB for all ranges. Figure 20 shows one result of the
calculated I/N at the BS and UE receivers for the MS due to the MSS downlink.

Figure 21 shows the distribution of the MSS uplink with an FR of 3 to evaluate the interference into the BS and UE for the MS with an FR of 1 as shown in Fig. 22.

Figure 23 shows the results of the calculated I/N at the BS and UE receiver for the MS at the reference cell due to the cofrequency MSS uplink as shown in Fig. 21. The results show that some ranges experienced a certain amount of unacceptable interference from the MES of the MSS. The maximum I/N values were 20.17 dB and 0.19 dB at the BS and UE receivers for the MS, respectively.

We also investigated the interference impact by an MSS system with a larger FR. Figure 24 shows the MSS uplink distribution with an FR of 7. The number of cofrequency cells for the MSS uplink was decreased to 5.

We investigated the interference impact on each BS and UE for the MS in the four cofrequency cells as shown in Fig. 19.

We calculated the I/N at the BS and UE receivers for the MS in each selected position due to the MSS uplink and found that the interference impact due to the MES with an FR of 7, which is larger than 3, would definitely decrease and would meet the interference criterion of −10 dB for all ranges. Figure 25 shows
one result of the calculated I/N at the BS and UE receivers for the MS due to the MSS uplink.

**B. Analysis of Results**

If a frequency reuse scheme is applied in an MSS system, it requires an FR of 7 to avoid any unacceptable interference from both uplink and downlink of the MSS system to the MS system.

As the result of sensitivity analysis according to the position of reference cell for the MS system, it was found that there is little effect of the cell position of the interfered MS system on the interference due to the much smaller cell size of the MS system compared to that of the MSS system.

**IV. Conclusion**

In this paper, we presented interference scenarios and a methodology to evaluate cofrequency interference between MSS and MS systems. Taking into account practical deployment environments, we conducted computational simulations to find the feasibility of coexistence between these systems in cofrequency bands.

As a result of this study, we found that, with an appropriate deployment plan for an MSS system, an MS system could operate without any unacceptable interference in a cofrequency in the same geographical area.

In spite of this, coexistence between the MSS and MS systems is likely to be difficult, with some interference paths that would result in extremely high levels of interference. This is primarily due to high levels of aggregate interference from the MS system into the MSS uplink. However, if appropriate geographical separation is considered when planning the MS system deployment, frequency sharing could be possible. There is some potential for an MSS downlink operation cofrequency with the MS system, but this would require certain separation distances between the MSS and MS service coverages.

The methodology proposed in this paper can be used when planning the deployment of MSS and MS systems to avoid the impact of unacceptable interference between them.

**References**


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