CO-CHANNEL INTERFERENCE IN SATELLITE-BASED CELLULAR COMMUNICATION SYSTEMS

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ABSTRACT

This paper presents the results of the development of a user-friendly software tool that can be used to calculate co-channel interferences, both in the downlink and in the uplink, of a single satellite/space-based mobile communications system, due to the reuse of frequencies in spot beams or coverage cells. The analysis and computer code can be applied to any type of satellite or platform elevated at any height above earth. The cells or beams are defined in the angular domain, as measured from the satellite or the elevated platform, and cells are arranged in a hexagonal lattice and overlap to provide complete coverage.

INTRODUCTION

Interference is inherently detrimental to a communications system. The type of interference that a system designer should be aware of depends on the system in reference. Interference could be classified as intra-system or inter-system interference. Out of band emissions of one system that interfere with another system in an adjacent band is an example of inter-system interference, whereas, co-channel interference within a system is an example of intra-system interference. The focus of this paper is intra-system interference, mainly co-channel interference.

In the case of a satellite based communications system, intra-system interferences that are of primary importance are intermodulation and co-channel interferences [1]. Intermodulation occurs due to the non-linear mixing of two or more different frequencies that fall within the passband of a receiver. On the other hand, co-channel interference occurs when there are two or more simultaneous transmissions on the same channel [2]. This type of interference is inherent in any system that employs a frequency reuse methodology.

Similar to terrestrial cellular systems employing frequency reuse at two base stations that are separated by some distance, a satellite or platform based communications system can also reuse frequencies in spot beams that form coverage cells separated by some distance on earth. A system designer must be aware of such reuse and the potential for co-channel interference. If designers can calculate the co-channel interference, they will be equipped with one more tool to manage their link budget calculations and to optimize their designs. The software tool developed to arrive at results presented in this paper calculates the co-channel interference for a satellite or an elevated platform based telecommunications system employing frequency reuse in different spot beams. Figure 1 shows a simplistic diagram of the co-channel interferers in both the uplink and the downlink.

ASSUMPTIONS

Some noteworthy assumptions that are made in the development of the software tool are listed as follows:

- A single satellite or elevated platform based spot beams provide the frequency reuse scenarios assumed.
- Spot beams have a user-specified pattern or beamwidth and provide overlapping coverage at X-dB level below the beam peak. The overlap, at least at the center of coverage, is enough to provide continuous coverage. Figure 2 illustrates this for cells that would ideally be at or near the sub-satellite point.
- Coverage on earth is continuous and follows an overall hexagonal pattern. The spacing in the angular domain between any two adjacent spot beams is the same. This along with the same beamwidth spot beams implies that the cells that are formed at the edges of coverage would cover a larger surface area.
- For satellite signals the transmit power is the same for all spot beams.
- The satellite gain pattern for all the spot beams is the same. This implies larger signal loss in the spot beams that are away from the center of coverage.

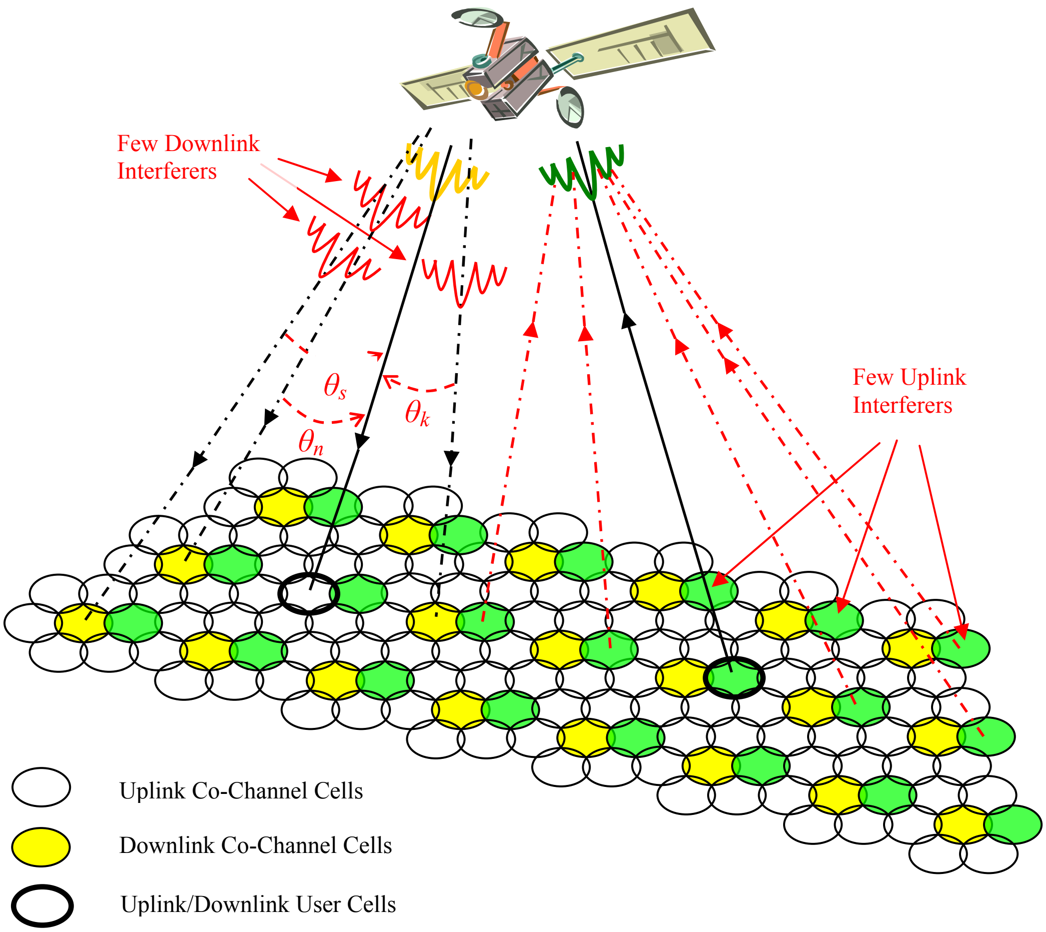

Figure 1. Depiction of the Satellite Uplink and Downlink Co-channel Interferers

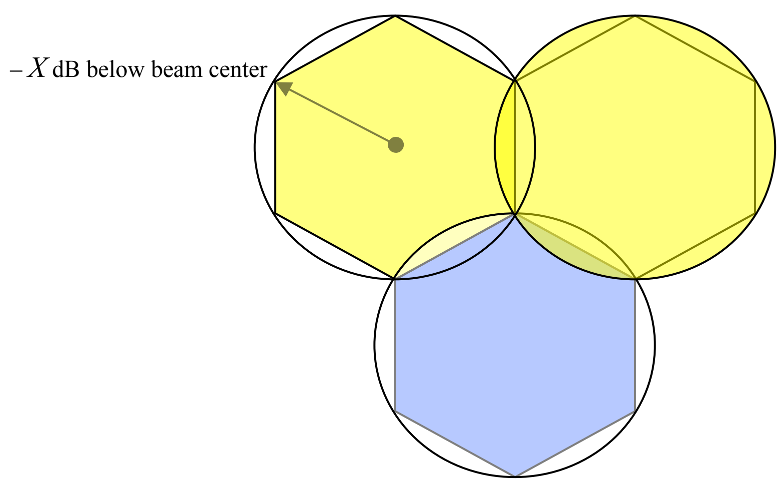

Figure 2. Spot Beams Providing Overlapping Coverage

CALCULATIONS

The calculation of the co-channel interference power in a receiver is crucial for a system designer. This leads to a more relevant performance measure: the overall carrier-to-noise ratio (CNR), which includes the interference components as follows [3]:

$$(C/N)_O = \frac{1}{\left[\frac{1}{(C/N)_{UL}} + \frac{1}{(C/N)_{DL}} + \frac{1}{(C/I)_O}\right]} \qquad (1)$$

Here, the overall carrier to interference ratio $(C/I)_O$ is calculated as follows [3]:

$$(C/I)_O = \frac{1}{\left[\frac{1}{(C/I)_{CC}} + \frac{1}{(C/I)_{IM}}\right]} \qquad (2)$$

The subscripts CC and IM indicate co-channel and intermodulation interferences, respectively. The $(C/I)_O$ may include all types of interferences that need to be calculated. The subject of our discussion in this paper is only co-channel interference. Therefore, the $(C/I)_O$ here includes only co-channel interference as follows:

$$(C/I)_O = \frac{1}{\left[\frac{1}{(C/I)_{CC-UL}} + \frac{1}{(C/I)_{CC-DL}}\right]} \qquad (3)$$

The downlink co-channel carrier-to-interference ratio $(C/I)_{CC\text{-}DL}$ is primarily a function of the reuse number and of the aggregate power due to the power in the sidelobes of interfering co-channel spot beams that is received in an earth station receiver. On the other hand, the uplink co-channel carrier-to-interference ratio $(C/I)_{CC\text{-}UL}$ is dependent upon reuse number and the number of co-channel users transmitting simultaneously and received at the sidelobes of the interfered beam. In this case, we'll assume that one user in each co-channel cell is transmitting. The placement of these co-channel users is random.

Calculations are made for a hypothetical and simplistic scenario. System parameters and their values that are input into the program are shown in Table 1. Some values for these parameters and the equations used in the program are taken from [3].

Table 1. Parameters and Values Used In Program Runs

Satellite Parameters	
Satellite/Platform Orbit and Altitude	LEO, Altitude = 2200 km
Satellite Transmit Power including Output Back-Off	− 10 dBW per channel per beam
Number of Spot Beams	37
Overlapping Coverage is at	− 4 dB below the beam center
Uplink Frequency / Downlink Frequency	1650 MHz / 1550 MHz
Antenna Gain @ 1650 MHz and 1550 MHz	23 dBi
Receiver Noise Temperature	500 K
Atmospheric Losses	0.5 dB
Contour Loss due to placement of Uplink/Downlink Mobile Terminals	2.6 dB
Receiver Noise Bandwidth (IF Bandwidth)	4.8 kHz
Mobile Terminal Parameters	
Transmitter Output Power	− 3 dBW
Antenna Gain (transmit and receive)	0 dBi
Receiver Noise Temperature	300 K

RESULTS

The program was run for different reuse values and for different pattern taper values of the satellite antenna communicating with the mobile terminals. Table 2 shows the effect of the different pattern tapers on the sidelobe levels [4]. The results of the program runs are shown in Table 3. It should be noted that the satellite antenna gain and its pattern-taper are the same for all beams that communicate with a mobile, irrespective of the link direction. In addition, as indicated in the parameters listed in Table 1, the overall link is between two L-band mobile terminals via the satellite.

Table 2. Sidelobe Levels Obtained For Different Taper-Illuminated Antenna Patterns

Taper Value	Sidelobe Level (*SLL*)	Illumination Distribution
0	− 17.6 dB	Uniform
1	− 24.6 dB	Parabolic
2	− 30.6 dB	Parabolic Squared

Table 3. Sample Runs Of the Program

Reuse #	Beam *SLL (dB)*	Downlink			Uplink			C/I_O (dB)
		# Tiers	# Cells	*C/I (dB)*	# Tiers	# Cells	*C/I(dB)*	
3	− 17.6	2	11	10.0	2	11	9.0	6.4
4		2	8	10.6	2	8	10.1	**7.4**
7		1	4	18.6	1	4	17.9	**15.3**
3	− 24.6	2	11	19.2	2	11	16.2	**14.4**
4		2	8	18.4	2	8	18.0	**15.2**
7		1	4	28.2	1	4	29.8	**25.9**
3	− 30.6	2	11	23.1	2	11	19.6	**18.0**
4		2	8	24.8	2	8	23.6	**21.2**
7		1	4	37.0	1	4	39.1	**34.9**
3	− 24.6	1	6	19.9	1	6	16.7	**15.0**
3	− 24.6	2	11	19.2	2	11	16.2	**14.4**

For the runs above the uplink and downlink carrier to noise ratios, excluding co-channel interference, are: $(C/N)_{DL}$ = 13.8 dB, $(C/N)_{UL}$ = 18.0 dB. As can be seen from the first three rows of Table 3, for the same sidelobe level, as the reuse number increases, the overall co-channel interference power decreases since *C/I* increases. It is also evident that, for the same reuse number, as sidelobe level of the spot beam antenna pattern decreases, the co-channel interference also decreases. The last two rows illustrate the fact that the overall interference power is very closely approximated by interference contributions from the co-channel cells in the first co-channel tier.

CONCLUSION

As evidenced from the results obtained above, the overall Carrier to Co-Channel Interference Ratio depends mainly on the system parameters such as the frequency reuse number, the spot beam's sidelobe level, and the number of active users and their separation from the main user. Unless the system uses antennas with very low sidelobe levels, employs less frequent frequency reuse or uses a combination of both, it will suffer from overall co-channel interference, which may become the limiting factor in the link budget analysis.

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