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Final Report

The Development of Sharing Criteria for Ka-Band Multi-Purpose Satellite Systems (KAMPSS)

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Summary

The World Administrative Radio Conference (WARC), held in 1992, allocated the frequency bands, 19.7-20.2 GHz and 29.5-30.0 GHz to both Mobile Satellite Services (MSS) and Fixed Satellite Services (FSS) on a co-primary basis for Geostationary Earth Orbit (GEO) satellites. An economic and flexible solution for the provision of both services is to place both MSS and FSS payloads on one multi-purpose satellite. Such a system is currently under study at CRC and is referred to as the Advanced Satcom Program which is intended to demonstrate on-board processing and Ka-band technologies in offering both MSS (land and aeronautical) and FSS to ground terminals equipped with small to very small antennas.

In order to determine the need for detailed interference coordination between satellite communications systems, sharing criteria, in the form of carrier-to-interference (C/I) ratios, are used. If adjacent systems meet the minimum C/I , there is no need for further interference coordination between the two systems. When the minimum C/I is not met, more detailed analysis of the interference between the two systems must be made. Since there are no currently established sharing criteria in the 30/20 GHz band for a mixture of MSS and FSS, there is a need to develop the analytical and software tools to develop such sharing criteria for co-primary operation in this frequency band. Timely development of sharing criteria will facilitate coordination of the Canadian system with its foreign counterparts and it will also develop ITU-R contributions to Working Party 4A. The KAMPSS software is intended to contribute to serving this need.

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1.0 General Overview

The elements in the analysis required in the study of GEO satellite communications system interference include

1. System spatial geometry;
2. Transmit power;
3. Propagation losses;
4. Antenna beam pattern definitions;
5. Services and frequency overlap;
6. Interference calculation.

The system position geometry is determined by the orbits of the satellites and the location of ground stations on the Earth's surface. Because the GEO orbit is such that, at nominal orbit position, a satellite is stationary with respect to the Earth's surface, the fundamental geometry is static. The angular relationships in the geometry of the system are determined by the angular disposition of antennas as required by each satellite link. Figure 1 illustrates the fundamental geometry of a system of satellites (not necessarily operationally related). Although it shows only two satellites, it captures the essence of the physical configuration.

With respect to communications systems requirements, orbit spectrum utilization concerns the relationships amongst system design factors, the communication capacity of the geostationary orbit and some part of the radio frequency spectrum. The number of satellites that can be placed in a given arc, or inversely, the average inter-satellite spacing, $\Delta\theta$, is often used as a measure of the orbit utilization. This measure of orbit utilization is related to systems' design factors, as well as to factors related to the environment. A significant factor is interference level. The constraint in orbit utilization is the interference which inevitably results between geostationary satellite networks and which prevents arbitrarily close spacing. The most useful measure of the interference is the C/I ratio, or alternatively, the CIR. It is defined as the ratio of desired signal power to undesired signal power at the output of the desired signal's receiving antenna.

2.0 Objectives of the Work

The overall general objective of this work is to develop sharing criteria between multi-purpose satellite systems operating in the 30/20 GHz band to allow the introduction of MSS and FSS in an orderly manner resulting in an efficient use of the geostationary orbit and frequency spectrum.

To meet this goal the technical objectives for the work adopted for the KAMPSS development were:

1. To develop software tools to analyze the impact of satellite orbit spacing on the C/I ratio and conversely the impact of the C/I ratio on the satellite orbit spacing;
2. To generate system curves showing the impact of system parameters on

satellite spacing, given objective C/I ratios, and conversely the impact of system parameters on C/I ratios given satellite spacing,

3. To develop a stand-alone program operating on a Macintosh personal computer, designed to allow the user to study downlink and uplink interference under different scenarios through a minimum set of user-definable parameters, namely,

   i) Choice of repeater type or fully regenerative payload for both the interfering and wanted satellite for downlink interference,
   ii) Choice of repeater type or fully regenerative payload for the satellite in uplink interference calculations,
   iii) Modulation and demodulation type,
   iv) Error correction coding,
   v) Satellite access scheme,
   vi) Bit error rate objectives,
   vii) Antenna gain patterns and sizes,
   viii) Satellite frequency re-use patterns;
   ix) Propagation losses;
   x) RF characteristics of transmitters and receivers,
   xi) Antenna pointing angle accuracy,
   xii) Availability,
   xiii) Impact of fade countermeasures;

4. To develop the program as a highly interactive tool and to allow the user to save/retrieve scenarios to/from files once defined.

3.0 Problem Statement

The problem involves interaction of GEO satellite communications networks and the orbit spacing relationships necessary to obtain optimum use of this resource while yielding acceptable levels of interference.

The systems of interest are those systems communicating in the 20-30GHz band. Realistic evaluation of the interference scenario requires an adequate simulation of the geometry and proper determination of the propagation losses to be able to establish transmit power requirements of the networks selected for study. In addition, adequate models of beam patterns are essential for good accuracy. Realism in the types of service, their access schemes and modulation schemes, their bandwidths are necessary in the determination of the interference situation.

The principal interest is in providing the means to determine characteristic curves for the carier-to-interference ratios for the services specified by the user as a function of orbital separation of the interfering systems, with the interest being focused on a "wanted" system.

4.0 Problem Solution

4.1 Geometry

In order to establish the basis for the analytical framework, the general geometry for the interference analyses is based on a static, three dimensional (and 4π steradian) geometry, with the origin of the reference frame coincident with the centre of the Earth. This permits the specification of ground station positions and the GEO satellite positions to be provided as geodetic coordinates.

In the case of ground stations, a transformation provided to transform position data into the ground station local reference frame from which range, azimuth angle and elevation angle is calculated. Position data may be subsequently transformed to each antenna local reference frame referred to the boresight axis. This permits computation of the antenna gains in the direction of relevant transmitters and/or receivers, which are functions of the antenna off-axis angles.

In the case of satellites, a transformation is provided to transform all position data into a satellite body-fixed reference frame with origin at the position (centre of mass) of the satellite; that is, the axes are respectively coincident with the direction of the spacecraft velocity vector, the normal (south) direction of the orbit plane and the inverse-direction of the satellite's Earth radius vector. A transformation is provided to transform data from the satellite body-fixed reference frame to the reference frame referred to the boresight axis. As in the case of ground stations, this permits computation of the antenna gains in the direction of relevant transmitters and/or receivers, which are functions of the antenna off-axis angles.

This overall geometry provides a straightforward basis for all study configurations.

4.2 Transmit Power

Each uplink and downlink transmit power for each network is computed based upon the the carrier-to-noise density ratio required for particular access schemes (FDMA/TDMA, CDMA), modulation schemes (MSK, BPSK, QPSK, M-ary PSK) and bit error rate specified, the transmitter gain, the propagation path losses (see below) and the properties of the receiver.

4.3 Propagation Losses

Propagation losses included are the free space loss, losses due to atmospheric gases, rain fading, tropospheric scintillation fading and angular pointing error of the transmitter/receiver. These losses are applied directly in the determination of the transmit power and wanted received power, although in the case of the fading losses these are applied as root-sum-squares. In the case of interfering signals, fading losses are not applied. In addition, the pointing error is assumed to always worsen the interference problem; that is, it is applied as a "negative" loss to interfering source signals.

4.4 Antenna Beam Patterns

All beam patterns are assumed to be rotationally symmetric about the boresight axis. Options include the FCC/CCIR specification, the modified CCIR specification, the Krauss model and a data array from which straight-line interpolations are made.

4.5 Services and Frequency Overlap

The current implementation of KAMPSS allows the storage of 100 service definitions, with a maximum of 20 active services.

It is assumed that if there is no frequency band overlap of the service bandwidth by a potential interfering signal that the interference is negligible (zero). If an overlap occurs, the frequency band defined by the overlap represents the frequency limits over which the interfering signal power spectral density function is integrated to determine the interference power. For

TDMA/FDMA services the received power spectral density function is assumed to have a Gaussian distribution. For CDMA services, the power spectral density function is assumed to have a uniform distribution.

4.6 Interference Calculations

The C/I ratios for each uplink service and each downlink service are computed as well as the total uplink/downlink power for each service. The angular separation of the satellites can be varied in discrete steps to provide a variation of the separation and thus yield characacteristic variation of C/I accordingly.

5.0 Conclusion

SSE utilized third-party commercial development and support tools to aid in the development and control of the software implementation, including in particular, the Language System FORTRAN Compiler which has tools for plotting and graphical displays. Also, SSE used the AppMaker application generator. FORTRAN Tools for AppMaker automatically generate clear, well-documented source code in Language Systems FORTRAN. All software was developed, maintained and managed within the Macintosh Programmer's Workshop (MPW) software development system. MPW also provides, through Projector, source management facility control and audit trails for all developed source code across the complete project development cycle and programming staff. The graphical user interface (GUI) was developed as user-friendly and adheres to Apple's Human Interface Guidelines.

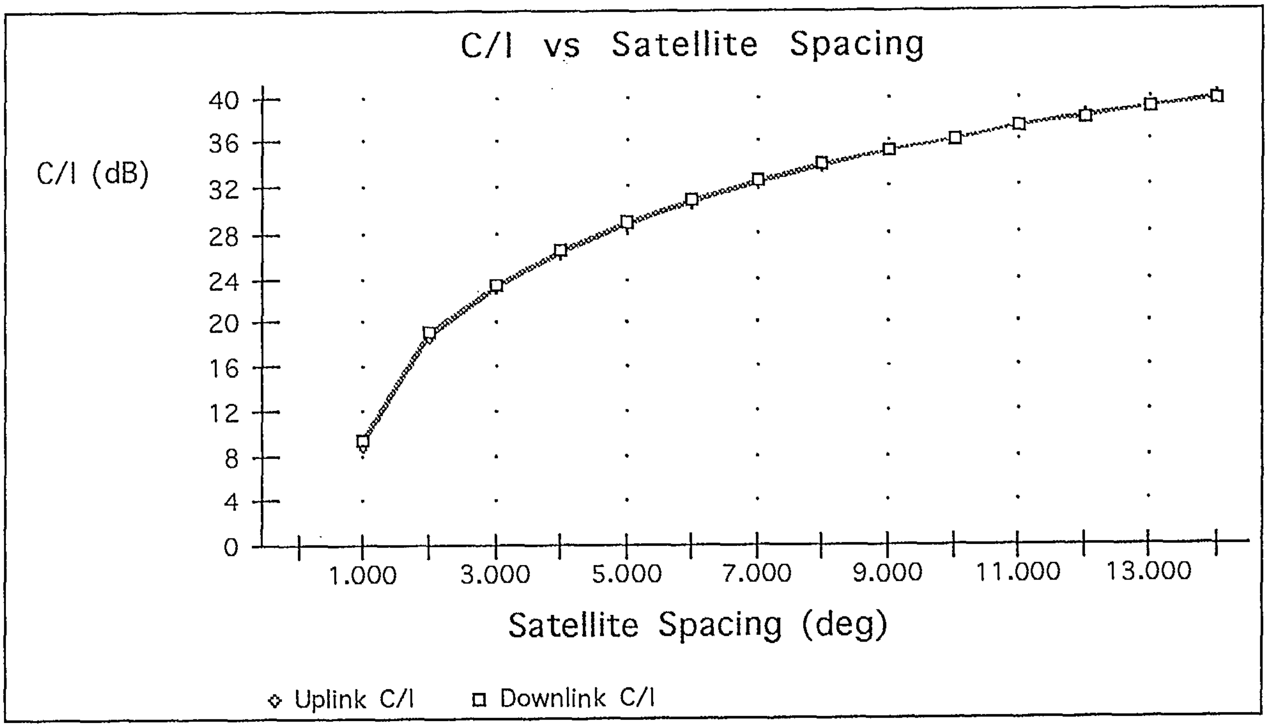
A representative output from KAMMPS, showing a system curve and table of results, along with the set-up are included in Appendix A.

Appendix A

Representative System Curve and Table

KAMPSS System Tables

Wanted Position	Int. Position	Spacing	Uplink C/I	Downlink C/I
(deg)	(deg)	(deg)	(dB)	(dB)
246.000	245.000	1.000	8.924	9.234
246.000	244.000	2.000	18.680	18.996
246.000	243.000	3.000	23.088	23.367
246.000	242.000	4.000	26.216	26.459
246.000	241.000	5.000	28.652	28.848
246.000	240.000	6.000	30.625	30.793
246.000	239.000	7.000	32.301	32.431
246.000	238.000	8.000	33.751	33.844
246.000	237.000	9.000	35.020	35.084
246.000	236.000	10.000	36.168	36.188
246.000	235.000	11.000	37.197	37.182
246.000	234.000	12.000	38.133	38.083
246.000	233.000	13.000	38.991	38.906
246.000	232.000	14.000	39.780	39.663


C/I vs Satellite Spacing
C/I (dB)
40
36
32
28
24
20
16
12
8
4
0
1.000
3.000
5.000
7.000
9.000
11.000
13.000
Satellite Spacing (deg)
◇ Uplink C/I
□ Downlink C/I

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