

REPORT ITU-R BO.812-4

**COMPUTER PROGRAMS FOR PLANNING BROADCASTING-SATELLITE
SERVICES IN THE 12 GHz BAND**

(Question ITU-R 85/11)

(1978-1982-1986-1990-1994)

1. Introduction

During the preparatory work for planning BSS in Regions 1 and 3 (WARC-77) and in Region 2 (RARC SAT-83), a certain number of synthesis computer programs were established to help planning. Although these programs are now obsolete in some aspects (software, computer used, etc.), a summary of the method used is useful.

Analysis programs have been established by the BR to assess the results of the plans during both conferences. Those analysis programs have to be used now when comparing results of the various synthesis programs.

2. Summary of synthesis programs

Synthesis programs are available to determine optimum beam size for arbitrary borders, optimum equivalent isotropically radiated power (e.i.r.p.), corresponding optimum receiver figure-of-merit G/T , optimum orbit positions for a set of non-homogeneous broadcasting satellites, and to plan compatible orbit locations, channel frequency, and polarization assignments, according to a variety of performance criteria and user requirements.

The following paragraphs provide a general description of the topics treated in the various programs. A list of the programs is given in the annex.

2.1 System configuration synthesis and cost evaluation

2.1.1 Purpose of the programs

The purpose of these programs is to determine a minimum cost satellite communication system subject to a variety of performance constraints and demands for service (both in terms of number of channels and station locations). The object is to determine the combination of key parameters, i.e., spacecraft e.i.r.p., earth-station antenna diameter, receiver noise temperature, and earth-station transmitter power, which minimizes a cost criterion, such as capital cost, or present worth. All the programs perform an exhaustive search, thereby guaranteeing that a global minimum is found. Two programs are aimed specifically at broadcasting satellites, while the third program treats telephony service and video together to find an overall system optimum.

A fourth program examines the cost impact of employing various spectrum saving techniques for both broadcasting and fixed service satellite systems, and provides a tool for maximizing the use of the orbit-spectrum. This program does not make orbital, frequency, or polarization assignments. More complete descriptions of the various programs are given in the reports submitted to the ITU-R as listed in the Annex.

2.1.2 *Satellite position optimization*

A non-linear programming technique was developed for the optimization of the orbital positions of a set of non-homogeneous broadcasting satellites with given characteristics. The optimization criterion is the minimization of the total arc occupied by all satellites. All transmissions are assumed to be co-channel and co-polar. The constraints to the optimization is the total carrier-to-interference ratio at each receiver due to the transmissions from all the other satellites. The order of satellites is not changed during the optimization procedure. Details of the technique used may be found in [CCIR, 1978-82a].

Another optimization process using a computer program developed in Japan has been reported by the ITU-R Secretariat [CCIR, 1978-82b]. Although this computer program was developed for application to the fixed-satellite service, it is felt that it may be of interest for the planning of the broadcasting-satellite service.

Relevant optimization procedures are also discussed in Report 453, § 8.2.2.

2.1.3 *Antenna beam optimization*

The WARC-BS-77 adopted elliptical (or circular) satellite-antenna beams for planning purposes. The ellipse was to be chosen to enclose a polygon whose corners were to be supplied by each administration to define its service area. To minimize the power at the satellite as well as the interference outside the service area, the ellipse should have the minimum area consistent with the desired coverage. Three computer programs are described below to determine the characteristics (boresight, dimensions, and orientation) of this ellipse.

2.1.3.1 *Program developed in Canada*

A computer program was developed in Canada [CCIR, 1978-82c, d; Chouinard, 1981a, b] in which spherical trigonometry is extensively used to simplify the optimization of circular and elliptical beams to a two-dimensional numerical convergence process. This convergence process is fully automated and the program is of an interactive type allowing the user to modify system parameters and control the program execution. Allowable pointing and rotation errors of the transmitting antenna as well as rain attenuation are taken into account in the calculation of the minimum elliptical beam parameters and required e.i.r.p. The transmit power is also given as an indication of the system practicability.

2.1.3.2 *Search program developed in the United States of America*

In this program [CCIR, 1978-82e; Akima, 1981], a series of searches is performed for sufficiently wide ranges of longitude and latitude of the boresight, orientations of the ellipse, axial ratios, and lengths of the major axis of the ellipse to determine the parameters of the minimum ellipse. Both the pointing tolerances and the orientation angle tolerance are taken into consideration during the search procedure. Computer time and cost depend on the step sizes of the parameters used during the searches. With a step size of 0.1° each for the latitude and longitude of the aim point, 1° for the orientation angle of the ellipse, 0.2 for the axial ratio, and 0.1° (as measured in satellite coordinates) for the major axis, the computing time for an average ellipse is about two seconds and the corresponding cost about \$0.70 (US) when the program is run on a CDC CYBER 170/750 computer.

2.1.3.3 *Program developed in the United States of America using non-linear programming techniques*

In most complex optimization problems, solutions cannot practically be obtained by direct differentiation. Computer programs then use a method of successive approximations. The program is formulated in terms of an objective function whose value is to be minimized and one or more constraint equations. If either the objective function or any of the constraint equations are not linear, this technique is called a non-linear programming technique.

In this program [CCIR, 1978-82e], the constraint equations state that all of the given points must lie on or inside the ellipse. The equations are non-linear and have five parameters, related to the coordinates of the centre, its dimensions (major and minor axes), and its orientation with respect to a given reference line. Thus, the computer must make a search in five-dimensional space. This program uses a method described by Nelder and Mead called a polyhedron search.

Antenna pointing tolerances are incorporated into the constraint equations by requiring the constraint points to lie inside the ellipse by at least the directional tolerance, and by requiring that they remain within this tolerance when the ellipse is rotated one way or the other by the rotational tolerance.

Additionally, the program computes the power necessary to produce a given e.i.r.p. from the satellite, taking into consideration the rain zone of the service area, the atmospheric attenuation model used, and the minimum elevation angle at any of polygon points.

2.1.3.4 *Further optimization*

The above processes describe optimization of e.i.r.p. contours. In some instances the resulting power flux-density over the service area exhibits a large spread due to varying climatic conditions within the area.

A further stage of optimization [CCIR, 1978-82d] reduces the spread of power flux-density by iteratively reducing the constant gain contour in such a way that the minimum required signal power is met or exceeded at each vertex of the polygon defining the required service area for the given climatic conditions. This process further reduces the required satellite power and also the potential for interference.

2.2 *Assignment of orbit, spectrum, and polarization for multiple users of broadcasting satellites*

The following programs provide alternative computerized methods for generating frequency, orbit and polarization assignments for broadcasting satellites. In general these computer programs devise plans to transmit one television programme per service area, but may also be used for certain non-regular channel assignment scenarios.

In the computer programs developed by Télédiffusion de France (TDF), the program is divided into three parts which separately and successively assign channels, position on the orbit, and polarizations. In the case of the channels, co-polar and cross-polar matrices of the emission discrimination are considered and assignments are chosen to avoid the same or adjacent channels being used by service areas which are potentially the most subject to mutual interference, that is, service areas corresponding to the smallest terms in the matrix. The aim of the assignments is, therefore, to eliminate those cases having the highest potential for interference. The orbital positions and the polarizations are then determined so as to give the maximum possible value of protection margin to the service area which is the most subject to interference. From this aspect, the method does in fact optimize the plan.

In the computer programs developed by the RAI, the initial step is to assign positions on the orbit according to the particular requests of the various services areas. As these positions are specified from the start, it is not necessary to calculate several beams for each service area nor to calculate the emission discrimination matrices, and it is possible to proceed directly to the calculation of the interference matrix. The assignment algorithm is based on the examination of a compatibility matrix, which shows whether two service areas can, or cannot use the same channel or the adjacent channel and the same polarization. Using operational-research methods, polarizations and then channels are assigned in such a way as to minimize the total number of channels required in the planning, subject to the condition that no service area has a negative protection margin. The initial assignments of positions can then be modified and the cycle of calculations repeated, in order to improve the results.

More recently [Carmassi and Tomati, 1983], the RAI's computer program has been improved by the extensive use of graph theory. The initial step is still the assignment of orbital positions to the various service areas. Then polarization, channels and minimum spacing between carriers (if needed to be determined) are computed with an optimized procedure (none of the possible solutions is omitted) according to the desired channel allocation framing for the RF bandwidth available.

Three additional methods of assignment of orbit, frequency and polarization for multiple users of broadcasting satellites have recently been developed and implemented on the computer in Canada in preparation for the RARC SAT-83. All methods can accommodate administrative operational constraints, e.g. multibeam satellites, specified orbital positions, channels and polarizations, etc.

The first method, BSS CAPS [Christensen, 1981; Leonard, 1981] features:

- the rapid evaluation of a single-valued objective function which is a measure of the severity of the total interference of the BSS plan being synthesized; and
- a menu of computer programs which enables the planner to successively make changes both manually and automatically in the assignments of channels and/or polarizations and manually in the assignment of satellite longitudes.