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. Althought 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.

By iteratively applying the various manual and automatic computer program options, the interference, as indicated by the objective function, is minimized. Since it was difficult to predict the exact planning methodology and constraints which will be favoured at RARC SAT-83, BSS CAPS was designed to provide a maximum of planning flexibility.

The second method, the minimum impact method [Nedzela and Sidney, 1981], starts from the minimum orbital separation matrices and produces a plan by simulataneously assigning a channel, an orbital position and a polarization to each service area in such a way that the number of possible assignments remaining for the next service area is maximized. To a first approximation this program gives an indication of the maximum orbit/spectrum capacity under the assumed constraints and provides a good starting point for further refinement by one of the other routines.

The third method [Chouinard and Vachon, 1981] using the "branch and bound" technique begins with an initial assignment of orbital positions from which the compatibility matrices are generated in a manner similar to the above RAI method. All possible simultaneous assignments of channels and polarizations are then generated. From these, the plan is extracted that meets:

- the single entry protection ratio;
- the aggregate protection ratio, and
- the minimum carrier spacing.

The exponential nature of this exhaustive assignment process required special techniques to limit the computing time. The program indicates those service areas that constrain the plan in order that the appropriate orbital positions may be modified.

The above three programs are designed to be used in a complementary fashion to provide maximum flexibility and insight.

3. Interference analysis programs

3.1 Introduction

To prepare the planning conferences, some administrations provided to the BR various interference analysis programs (see list in Annex 1).

For the conferences, the BR has derived from those programs its own software which has been used during the planning process.

The MSPACE computer software system has been developed by the BR to perform the analyses for the determination of the coordination requirements for the Plans for space networks in Appendices 30, 30A, and 30B of the Radio Regulations. These appendices deal specifically with the Plans established at WARC-77, RARC-83, and WARC ORB-88, World/Regional Administrative Radio Conferences.

3.2 MSPACE and MSPACEG

The computer programs MSPACE and MSPACEG are the main components of the MSPACE system. These are the programs which perform the actual analysis. They are similar, but with the following distinction:

- MSPACE performs the analysis using elliptical beams in all situations.
- MSPACEG performs the analysis using shaped beam contours (from the IFRB's "Graphics Interference Management System" (GIMS)) if the information concerning the shaped beam is available and elliptical beams in all other situations.

A complete analysis of the Plan (or portion of the Plan) can be performed. Alternatively, a detailed analysis of a specific channel of a specific beam at a specific position can be requested. Many intermediate results are available with the detailed analysis.

3.3 Description

MSPACE and MSPACEG change frequently to keep up with changing technology. The current version of the MSPACE system is described in the current version of the "Catalogue of Software for Radio Spectrum Management" which is published periodically by the ITU. Further details concerning the MSPACE system are given in the documentation supplied with the MSPACE software, which can be purchased by following the instructions in the "Catalogue".

3.4 Inputs

Both MSPACE and MSPACEG require an input file containing the parameters for the particular Plan, or portion of a Plan, to be analysed. Since there are six Plans, or portions of Plans, there are six possible input files. Each of these input files must be edited to ensure that it contains the appropriate beams for analysis, and that they have the proper parameters.

The format for these data files is essentially the same for each Plan or portion of a Plan, although some data elements may not be required in certain situations. In order to execute MSPACE, MSPACEG properly the user should be familiar with the various elements of the input data file.

MSPACEG also requires GIMS for input.

Many parameters are included in the input files, rather than being coded into the programs. Examples are pointing error, rotation error, and station keeping error. These can be set to zero if the effects of these errors are to be ignored.

3.5 Outputs

Depending on which option is chosen, there are either two or three output files from MSPACE and MSPACEG, plus a log file containing various messages from the program:

- the findings file, containing the list of situations where coordination is required. If no coordination is required, this file will be empty;
- the reference situation file, containing newly-calculated reference situations. This will be either for all beams or for only selected beams, depending on the option selected;
- the details file, containing the detailed intermediate results for a single beam. This is an optional file which is generated only when a detailed analysis of a single beam is requested;
- there is also an output log. When running interactively, this will be the screen of the terminal. Otherwise, it is the batch log file itself. This does not contain results of the analysis. Rather, it contains error messages, status messages (such as the number of the beam which is being processed), etc.

3.6 Hardware/software requirements

MSPACE and MSPACEG are written in ANSI FORTRAN 77. MSPACE should be easily convertible to any environment supporting FORTRAN 77. However, because MSPACEG requires the GIMS package and data file, it is not easily transportable.

Within the IFRB, MSPACE and MSPACEG both run on the ITU's Siemens Mainframe. In addition, MSPACE is available on an IBM PC* (or compatible) running under DOS, using Microsoft FORTRAN Version 5.0.

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* MSPACEG is not available on the PC because it requires the GIMS data file, and the GIMS data file is not available on the PC.

3.7 Limits

There are various internal limits in MSPACE and MSPACEG:

- the maximum number of beams that can be analysed at one time is 350;
- the maximum number of channels per beam is 20;
- the maximum number of test points per beam is 10 for the uplink, and 10 for the downlink;
- the maximum number of single-entry contributions to a beam which exceed that allowed by Appendix 30B is 20.

These can be easily modified by changing PARAMETER statements in the programs. However, any increases may lead to difficulty in fitting MSPACE within the DOS limits.

4. Additional considerations

4.1 *Shaped-beam considerations*

The programs discussed in this Report include only one that deals, as part of an analysis program, with shaped beams, whereas such beams may be desirable for efficient spectrum – orbit utilization and efficient utilization of space station power. The use of shaped beams is being studied by some administrations, and *additional* computer programs to incorporate such beams in the *analysis* process are being developed. The analysis program used during the RARC SAT-83 did not include such a capability but did include the capability of using a "rapid roll-off" pattern as an option to the standard reference pattern for the space station transmitting antenna (see Final Acts, WARC ORB-85). Computer programs of this type may be necessary for planning the broadcasting-satellite service in the future in order to handle such beam specifications as some administrations may submit. Further study of the desirability and feasibility of incorporating shaped beams in planning programs is required.

4.2 *Computer tools for simultaneous planning of the broadcasting-satellite service and feeder links*

When the planning of the broadcasting-satellite service (BSS) and the associated feeder links (AFL) proceeds independently, two separate computer programs will be required to test and evaluate the separate BSS and AFL plans. These programs will be similar, but they will also have distinct features, particularly with respect to the input parameters. When the BSS and the AFL are planned simultaneously and together, the computer tools required comprise more than a combination of the two separate programs. The following features are desirable in a combined BSS and AFL computer analysis program to test and evaluate complete BSS and AFL plans, particularly those that take advantage of the added flexibilities made possible by simultaneous planning:

- maximum flexibility to handle unforeseen conditions and changes in parameter values or models;
- the capability of determining the feeder-link locations giving rise to the worst feeder link C/I;
- the capability of analyzing feeder-link plans separately, BSS plans separately, or both together;
- the capability to allow independent specification of feeder link and BSS frequencies and service areas and to allow any connections between the two;
- the capability to specify feeder-link power in terms of either e.i.r.p. or C/N at the satellite, including the proper rain margins;
- the capability to accommodate possible non-standard systems.

ANNEX I

LIST OF DOCUMENTS AND REFERENCES

1. Synthesis programs

1.1 *System configuration synthesis and cost evaluation*

CCIR Doc. 11/136 (USA) [1974-78] Computer programs for planning broadcasting-satellite systems.

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1.2 *Satellite beam optimization*

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2. Interference analysis programs

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