NASA Technical Memorandum 100244

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(NASA-TM-100244) AN ALLOTMENT PLANNING CONCEPT AND RELATED COMPUTER SOFTWARE FOR PLANNING THE FIXED SATELLITE SERVICE AT THE 1988 SPACE WARC (NASA) 12 p Avail: NTIS HC A03/MF A01 CSCL 17B G3/32
N88-11944
Unclas
0109762

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Prepared for the
Global Telecommunications Conference
sponsored by the Institute of Electrical and Electronics Engineers
Tokyo, Japan, November 15-18, 1987

NASA

AN ALLOTMENT PLANNING CONCEPT AND RELATED COMPUTER SOFTWARE FOR PLANNING THE FIXED SATELLITE SERVICE AT THE 1988 SPACE WARC

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E-3777

SUMMARY

This paper describes a two-phase approach to allotment planning suitable for use in planning the fixed satellite service at the 1988 Space World Administrative Radio Conference (ORB-88). The two phases are (1) the identification of predetermined geostationary arc segments common to groups of administrations, and (2) the use of a synthesis program to identify example scenarios of space station placements. The planning approach is described in detail and is related to the objectives of the conference. Computer software has been developed to implement the concepts, and a complete discussion on the logic and rationale for identifying predetermined arc segments is given. Example scenarios are evaluated to give guidance in the selection of the technical characteristics of space communications systems to be planned. The allotment planning concept described guarantees in practice equitable access to the geostationary orbit, provides flexibility in implementation, and reduces the need for coordination among administrations.

1.0 BACKGROUND

The 1985 Space World Administrative Radio Conference (ORB-85) determined that the fixed satellite service in certain frequency bands shall be subject to allotment planning. The key features of the allotment planning method are:

"An allotment Plan that shall permit each administration to satisfy requirements for national services from at least one orbital position, within a predetermined arc and predetermined band(s). The allotment Plan shall be established in the bands:

4500 to 4800 MHz and 300 MHz to be selected in the band 6425 to 7075 MHz; and

10.70 to 10.95 GHz, 11.20 to 11.45 GHz, and 12.75 to 13.25 GHz;"

Furthermore, "The bandwidth associated with each allotment shall be 800 MHz." With frequency bandwidth removed as a variable, the allotment planning task is reduced to an effort to define "an allotment plan that shall permit each administration to satisfy requirements for national services from <u>at least one orbital position within a predetermined arc.</u>"

The allotment planning concept defined in this paper allows administrations to satisfy their requirements from <u>any one of a number of possible orbital positions within a predetermined arc</u>.

2.0 APPROACH TO ALLOTMENT PLANNING

The general approach proposed for allotment planning consists of two phases:

Phase 1: Identification of predetermined arc segments common to groups of administrations. Those administrations within a group and sharing a common predetermined arc segment would be able to position individual space stations at any one of a number of possible orbital positions within the arc segment.

Phase 2: Use of a synthesis computer program to identify example scenarios of space station placements. Given N space stations to be placed in a predetermined arc of X degrees, repeated runs of the synthesis program would identify acceptable space station placement scenarios within the arc segment, subject to other constraints such as carrier-to-interference ratio, space and ground antenna characteristics, and other technical parameters.

Completion of these two phases of the allotment planning approach will have identified an allotment plan that would permit each administration to satisfy its requirements from any one of <u>a number of possible orbital positions within a predetermined arc</u>. At the conclusion of the second phase, one of the outputs of the planning process might be as shown in figure 1, for a portion of the geostationary orbit. Figure 1, further described in section 4.0, highlights three features of the allotment planning process:

(1) Predetermined arcs may have different sizes

(2) Different arc segments may have different numbers of space stations grouped within them

(3) The density of space stations per degree of orbit may vary

3.0 SOFTWARE DEVELOPMENT FOR ALLOTMENT PLANNING

Software to identify possible predetermined arcs and associated groupings of administrations (i.e., Phase 1), has been developed within the United States at the NASA Lewis Research Center and is discussed in sections 3.1 and 3.2 of this paper. The software package is entitled NASARC (Numerical Arc Segmentation Algorithm for a Radio Conference). References 1 and 2 contain details of the NASARC concept and its implementation. NASARC is used with a general synthesis program, that can identify example placements of space stations subject to the constraints of the predetermined arcs and the groupings of administrations (i.e., Phase 2), to develop an allotment plan for a given set of technical constraints. An applicable synthesis program, ORBIT-II, was developed by Kokusai Denshin Denwa Co., Japan, and has been accepted by the International Frequency Registration Board (IFRB) for use at the 1988 Space WARC. Section 3.3 of this paper describes how the NASARC predetermined arc program and the ORBIT-II synthesis program may be used together to accomplish allotment planning. The reader is referred to reference 3 for a detailed description of ORBIT-11.

3.1 Calculation of Possible Predetermined Arcs and Groupings of Administrations

The first program element of the NASARC software package determines an exhaustive list of "compatible" groups of satellite service areas, and a potential predetermined arc segment associated with each group over which the group may exist. Each "compatible" group consists of several service areas that are sufficiently separated geographically so that co-location or near co-location of their satellites will result in achieving a user-specified single-entry downlink carrier-to-interference ratio (C/I). The program operates upon a set of basic requirements (including service areas, service arcs, and antenna beam dimensions) subject to a variable set of technical parameters (such as antenna gain patterns, target carrier-to-interference ratio, and ground antenna size) to assess compatibility between all possible space station pairs.

Pairwise (single-entry) compatibility between systems is assessed on the basis of the satellite separation required to allow systems serving each service area to meet the desired carrier-to-interference ratio. A user-supplied "grouping criterion" is utilized as the basis of this assessment. The grouping criterion expresses, in degrees of orbital arc, the maximum allowable required satellite separation defining pairwise compatibility between systems. Each pair of systems is compatible if the required carrier-to-interference ratio is achieved at the orbital separation defined by the grouping criterion, when each system in turn is regarded as "wanted" and "interfering". The carrier-to-interference ratio achieved is calculated on the basis of antenna discrimination on the downlink. That is, the fall-off from on-axis gain of the interfering satellite transmit antenna in the direction of the wanted earth station receiver is combined with the fall-off of the earth station receive antenna in the direction of the interfering satellite to obtain the total antenna discrimination available for the given satellite separation.

Compatibility is assessed, in the manner described above, for all possible pairings of satellite systems at a discrete arc location. This assessment is followed by construction of a corresponding "compatibility" matrix for the current arc location. If the orbital spacing specified by the user-supplied grouping criterion allows the target carrier-to-interference ratio to be achieved at the current location, a one is placed in the appropriate locations of the compatibility matrix. In any other case, a zero is placed in the appropriate matrix locations. Thus, the symmetric compatibility matrix expresses, in ones and zeros, all pairwise compatibilities possible at a discrete arc location.

The compatibility matrix for a given arc location may be regarded as a collection of vectors that expresses, for each system, all possible pairwise compatibilities with other systems. By exhaustive examination of each vector, all possible groups of service areas, whose members are each compatible with all other group members, may be found. Thus, unique compatible groupings are enumerated at each discrete arc location considered by the program.

The span of arc locations over which each unique grouping may occur is determined by merging the lists of groupings generated at each arc location. The final output of the first program element of the NASARC software package, therefore, consists of a listing of all unique compatible groupings of service areas, and the east and west longitudinal boundaries over which each grouping may exist. These arc spans, referred to as group arcs, may be considered as upper bounds on the predetermined arc available to each grouping.

The first element of the NASARC software package clearly demonstrates the relationship between choices in technical parameters and amount of orbit re-use obtainable via grouping of compatible service areas. Selection of technical parameter values representative of high-performance technologies results in larger groups of administrations sharing a given arc segment. Lower performance characteristics, however, result in smaller group sizes and may not allow solutions to the allotment planning problem.

3.2 Grouping Selection and Formation of Predetermined Arcs for an Allotment Plan

The second element of the NASARC software package, the predetermined arc (PDA) generation program, examines all of the available groupings with their corresponding arc segments and computes a common PDA for members of each selected grouping. The software proceeds through a heuristic process of choosing an appropriate grouping, computing the PDA length, and placing the group of compatible service areas in an open area of the geostationary orbit within the constraints of that group's available group arc. This process is repeated until all administrations have been considered and the requirements of the allotment plan, to "permit each administration to satisfy requirements for national service from at least one orbital position within a predetermined arc", have been satisfied. The process of selecting groupings and predetermined arc sizes is performed using several figures of merit (FOM) or selection criteria designed to solve the most difficult allotment problems first. This task requires the selection of groupings and predetermined arcs such that the requirements of all administrations are met before the available orbital arc is exhausted. This entire heuristic process is highly dependent on the choice of technical parameters initially used to find compatible groupings. For some sets of technical parameters, the requirements of all administrations can be successfully accommodated with some degree of flexibility. For other choices of technical parameters, a solution may not be found.

As stated previously, several figures of merit are used in the selection process in order to solve the most difficult allotment problems first, to maintain as much flexibility as possible, and to provide a reasonable opportunity for a successful allotment plan to be found. The first figure of merit is used to select a "critical" administration. This is done by choosing the administration which appears in the least number of groups. Selection of this administration preserves the maximum number of remaining groupings for subsequent allotments. It also allows the most limited administration, in terms of available groupings, to be handled first which preserves the possibility of accommodating all administrations in the planning process. If there is a tie at this step of the selection process, the administration with the smallest service arc is handled first.

The next step is to select a grouping which contains the critical administration, as determined by the first figure of merit (FOM1). Selection of the "critical" grouping is a two-stage process employing two figure of merit factors (FOM2 and FOM3) simultaneously. The first of these selection criteria (FOM2) is related to the desired grouping size, in terms of number of members, and the second criterion (FOM3) sets the predetermined arc length for a given grouping. The grouping selection process is configured such that the largest size grouping containing the critical administration which meets the predetermined arc length constraint is selected. If two or more groupings are of the same size and have group arcs which meet the predetermined arc length constraint, the grouping which has the largest available group arc is selected. The predetermined arc length is determined by the number of members within the grouping and by certain technical characteristics. The technical characteristics which affect the PDA length include the earth station antenna diameter, the required single entry C/I, and the grouping criterion (i.e., the specified orbital separation requirement for near colocation). The specification of an appropriate set of technical characteristics will be decided at WARC-88 with the guidance of activities to be carrier out during the intersessional period by the IFRB.

In order to maintain flexibility in the selection of specific orbit locations at the time of system implementation while minimizing the need for coordination, the grouping criterion should typically be selected to be one degree or less.

Once an appropriate grouping has been selected, it is given a temporary predetermined arc within its corresponding group arc. As subsequent critical administrations and critical groupings are selected, each is given a PDA of the calculated arc length in an open area of the orbital arc, somewhere within its group arc. These PDA's are temporary in that they are moved around within their group arcs during the allotment process in order to make room for subsequent allotments as necessary. When all of the administrations have been accommodated, the temporary PDA's become the final predetermined arcs for the allotment plan. Thus, with predetermined arcs defined in this manner, administrations would be able to position individual space stations at any one of a number of possible orbital positions within their allotted arc segments.

3.3 Identification of Example Space Station Placements

In the allotment planning concept described in this paper, a synthesis program is used to demonstrate that the allotment plan can "guarantee in practice for all countries equitable access to the geostationary satellite orbit." This is accomplished by identifying example space station placement scenarios within the predetermined arcs generated by the NASARC software package, subject to technical constraints such as carrier-to-interference ratio, space and ground antenna characteristics and other technical parameters. Another use of the synthesis program is to demonstrate the residual flexibility of the plan by identifying the existence of multiple space station arrangements that meet the technical constraints within the PDA boundaries generated by NASARC.

The synthesis program, ORBIT-II, is applicable to this task and is equipped to include the uplink interference contribution as well as the downlink. The effects of the uplink can therefore be considered when identifying example space station placements. Further, ORBIT-II can be used to aggregate the interference effects of all the space stations within a grouping as well as the interference effects due to space stations from neighboring groupings. Service arc boundaries for each space station in an ORBIT-II scenario would be set to the appropriate predetermined arc boundaries as generated by NASARC.

Separate ORBIT-II runs can be made on individual NASARC groupings, or a single run including all PDA's can be performed for a full aggregate interference analysis. The identification of the existence of multiple space station arrangements within the shared PDA's can be accomplished by varying the program's internal space station launching sequence. (Full details of the ORBIT-II synthesis program can be found in ref. 3).

4.0 APPLICATION OF THE ALLOTMENT PLANNING CONCEPT TO AN EXAMPLE SCENARIO

The concept just described and the associated software are applied to an example scenario to indicate the process by which an allotment plan may be achieved. Table I presents input parameters to the NASARC software for generation of predetermined arcs for a 55 service area scenario, consisting of 30 Region-1 and 25 Region 2 administrations. From these inputs, the NASARC software generates compatible groupings and, based on various figure of merit factors, selects appropriate groupings and their associated predetermined arc segments for use in constructing an example allotment plan.

Table II presents the NASARC final output data for the 55 service area scenario. The groupings selected and their associated predetermined arc boundaries are indicated in the table. Table II serves to show that different arc segments may have different numbers of space stations grouped within them, and that the density of space stations per degree of orbit can vary. It is important to keep in mind that the grouping sizes generated for this example scenario are a direct function of the number of service areas represented in the scenario. Larger scenarios will in general provide the opportunity for larger average grouping sizes, thereby allowing more efficient use of the orbit spectrum resource. This in turn will enhance the possibility for achieving a successful allotment plan.

The planning process is not complete until it can be demonstrated that every administration represented in the scenario can, in fact, be guaranteed the availability of an orbital position within their respective predetermined arcs. This can be accomplished through the use of the synthesis program, ORBIT-II, to identify example space station placements within the boundaries of the predetermined arcs generated by NASARC. The basic input parameters used in running the ORBIT-II program on the example scenario are given in table III. The spacecraft output power for each service area was calculated to approximate the constant power flux density assumption utilized in the NASARC software. The only other difference in input technical parameters between the NASARC software and the ORBIT-II program was in the spacecraft antenna. In NASARC the spacecraft antenna was chosen to be the RARC '83 standard roll-off antenna, as this was the antenna pattern being utilized in the IFRB's planning exercises. In the version of the ORBIT-II program utilized on this example scenario, only an empirical gain fall-off formula was available for use as the spacecraft antenna. Thus, an antenna decay constant of 4.0 was used to conservatively approximate the RARC '83 antenna roll-off characteristics.

In this exercise, two types of ORBIT-II runs were made to generate example space station positions within the NASARC generated predetermined arcs. First, each allotment group was run individually through the ORBIT-II program constrained to the predetermined arc. The results of these individual runs are displayed in figure 1. The individual runs show the effects of group members on each other and, because the groups were processed individually, the administrations are compressed towards the centers of their individual predetermined arcs. As can be seen in figure 1, only a small portion of each PDA is required to accommodate the members of each grouping, allowing for flexibility in orbit positioning or in the choice of system technical parameters at the time of implementation.

The second type of ORBIT-II run was an aggregate processing of all of the allotment groups simultaneously while still constraining the group members to their predetermined arcs. Results of the aggregate run are displayed in figure 2. The aggregate run, while demonstrating example space station positions, attempts to push the individual space stations towards the center of total available arc while keeping each of them within the constraints of their allotment group's PDA boundaries. More importantly, all of the space stations in the scenario exceeded the desired aggregate interference criterion of 26 dB which serves to validate the allotment planning concept based on a target single-entry interference criterion as presented in this paper. The aggregate case was also processed by ORBIT-II with a user-specified launch order; these results are presented in figure 3. These additional example placements of the space stations serve to illustrate the flexibility of positioning within the PDA. This flexibility also allows for variations in technical parameters of the individual administrations. Furthermore, because compatibility between the allotment group members has been assessed by the NASARC software, the level of coordination between group members is reduced.

5.0 CONCLUSIONS

This paper has presented a concept for an allotment planning procedure applicable to planning the fixed satellite service at the 1988 Space WARC. A two-phase approach has been outlined; (1) the identification of predetermined geostationary arc segments common to groups of administrations, and (2) the use of a synthesis program to identify example scenarios of space station placements to demonstrate the guarantee in practice of equitable access to the geostationary orbit. Computer software has been developed within the United States to implement the Phase 1 portion of the approach, and a description of the software and the rationale behind it has been given in the paper. The coupling of this program with an appropriate synthesis program (for Phase 2) has also been discussed. An example scenario has been presented showing the application of the planning concept to a 55 service area scenario consisting of Region-1 and Region-2 administrations. The allotment planning concept described guarantees in practice equitable access to the geostationary orbit, while providing flexibility in the implementation of space stations and reducing the need for coordination among administrations.

REFERENCES

1. W.A. Whyte, Jr., A.O. Heyward, K.J. Long, D.S. Ponchak, R.L. Spence, J.E. Zuzek, "Numerical Arc Segmentation Algorithm for a Radio Conference NASARC (Version 1.0) Technical Manual," March, 1987.

2. W.A. Whyte, Jr., A.O. Heyward, K.J. Long, D.S. Ponchak, R.L. Spence, J.E. Zuzek, "Numerical Arc Segmentation Algorithm for a Radio Conference NASARC (Version 1.0) User's Manual," March, 1987.

3. Kokusai Denshin Denwa Co., LTD., Tokyo Japan, "The Orbit Spacing Minimizer (ORBIT-II) User's Manual," April, 1984.

TABLE I. - NASARC INPUT PARAMETERS 55 SERVICE AREA SCENARIO

Single entry downlink C/I, dB	32.00
Downlink frequency, GHz	4.50
Antenna type, TX	RARC 83 standard Roll-off
Antenna type, RCV	32-25xlog(phi) Sidelobe envelope
E/S antenna diameter,m	4.50
Minimum ellipse beamwidth, deg	1.60
Grouping criterion, deg	1.00

TABLE II. - NASARC FINAL OUTPUT DATA

55 SERVICE AREA SCENARIO

Allotment groups, ITU country codes	PDA boundaries, degrees east	
EQA GUY USA	-96	-90
BRB CHL MEX	-87	-81
CAN GTM HTI PRU TRD	-104	-96
ARG BAH CPV LBR NCG	-58	-50
BEN GMB HND ISL	-47	-40
CUB GNB PNR	-64	-58
BLZ DOM	-115	-110
SLV VEN	-81	-76
CTR SEN	-40	-35
GNE GOO MLI MLT NMB	0	8
ALG FOO MTN TCD	-22	-15
BOO COG GHA MRC	-29	-22
EOO GAB SRL TGO	-15	-8
BFA POR STP	-8	-2
GUI JMC NIG	-35	-29
CLM	-119	-115
CME CTI	8	13

TABLE III. - ORBIT-II INPUT PARAMETERS 55 SERVICE AREA SCENARIO

Single entry C/I, dB	40
Aggregate C/I, dB	26
Downlink frequency, GHz	4.50
Uplink frequency, GHz	6.75
3-dB Beam-width, deg	0.800(1/2 HPBW)
Internal launching order	Try all & user specified
E/S Antenna diameter, m	4.5
E/S Transmit gain, dB	48.24
E/S Receive gain, dB	44.69
Satellite receive gain, dB	44.61
(D/Lambda) E/S transmit	101.69
(D/Lambda) E/S receive	67.77
E/S Side lobe peak/slope	32-25xlog(phi)
S/C Antenna decay constant (transmit)	4.0
S/C Antenna decay constant (receive)	4.0
HPA Output power	Variable to achieve constant PFD
PFD	-161.04 dBW/m2 in 4 kHz bandwidth

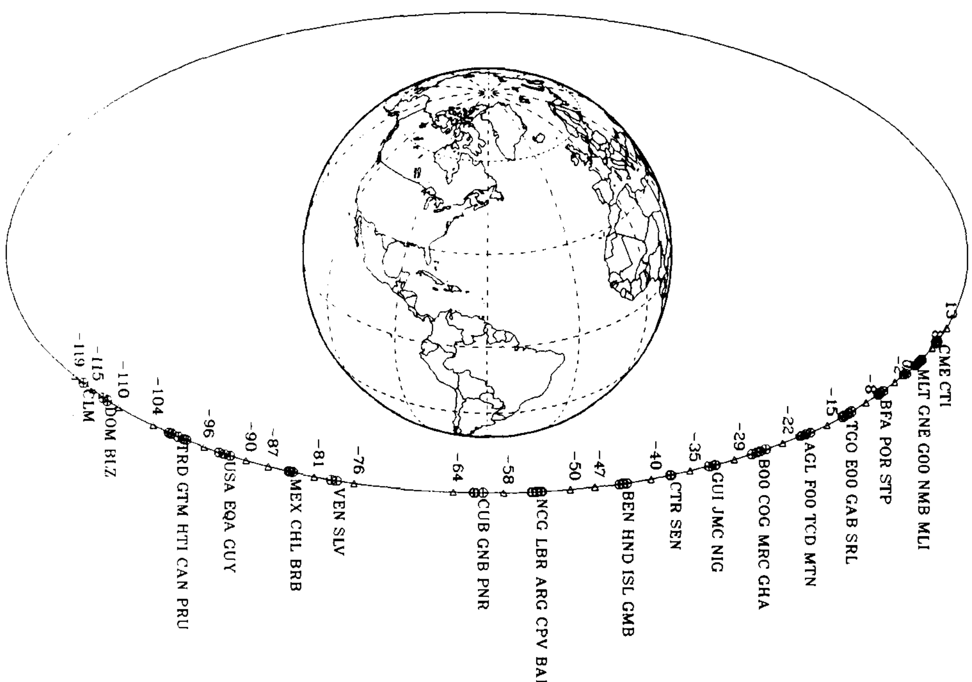

FIGURE 1. - EXAMPLE SPACE STATION PLACEMENTS (INDIVIDUAL ORBIT-II RUNS FOR EACH NASARC GROUPING).

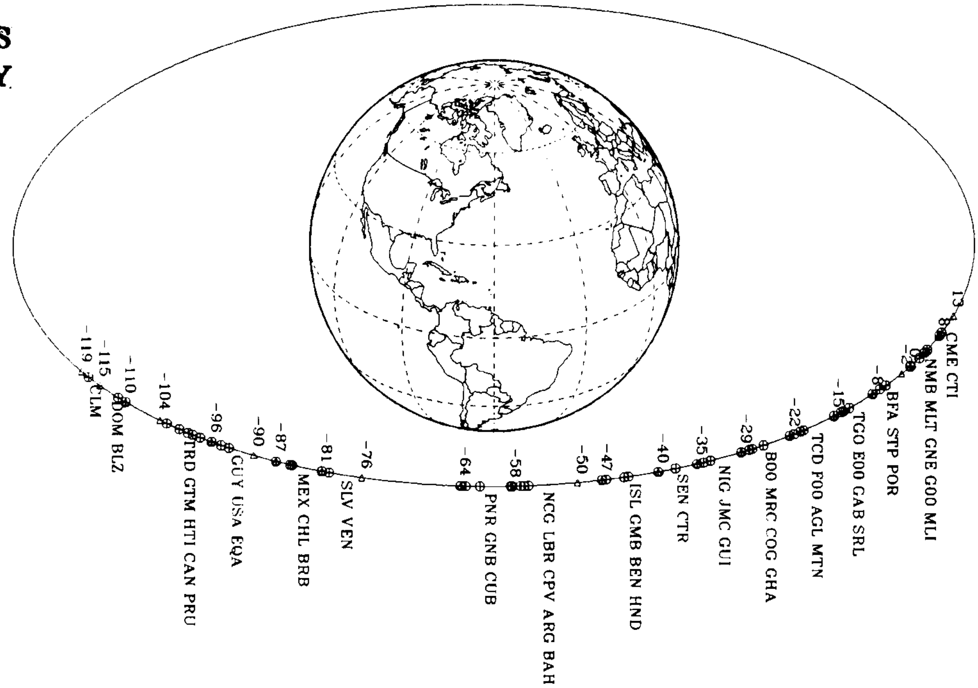

FIGURE 2. - EXAMPLE SPACE STATION PLACEMENTS (AGGREGATE ORBIT-II RUN WITH TRY ALL LAUNCHING ORDER).

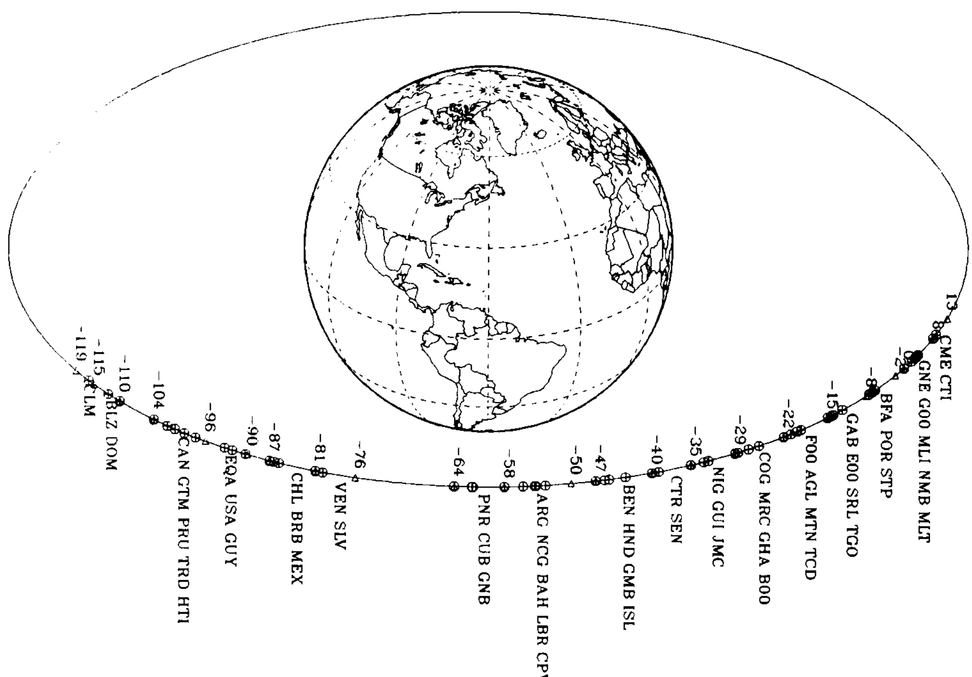

FIGURE 3. - EXAMPLE SPACE STATION PLACEMENTS (AGGREGATE ORBIT-II RUN WITH USER SPECIFIED LAUNCHING ORDER).

NASA National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-100244		

4. Title and Subtitle	5. Report Date
An Allotment Planning Concept and Related Computer Software for Planning the Fixed Satellite Service at the 1988 Space WARC	
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Edward F. Miller, Ann O. Heyward, Denise S. Ponchak, Rodney L. Spence, Wayne A. Whyte, Jr., and John E. Zuzek	E-3777
	10. Work Unit No. 643-10-01
9. Performing Organization Name and Address	11. Contract or Grant No.
National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191	
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, D.C. 20546-0001	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared for the Global Telecommunications Conference sponsored by the Institute of Electrical and Electronics Engineers, Tokyo, Japan, November 15-18, 1987.

16. Abstract

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17. Key Words (Suggested by Author(s))	18. Distribution Statement
Satellite communications Planning Software	Unclassified - Unlimited Subject Category 32

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No of pages	22. Price*
Unclassified	Unclassified	11	A02

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161