ENGINEERING CALCULATIONS FOR COMMUNICATIONS SATELLITE SYSTEMS PLANNING

C.H. Martin
D.J. Gonsalvez
C.A. Levis
C.W. Wang

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21000 Brookpark Road
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16. Abstract (Limit: 200 words)

Progress is reported on a computer code to improve the efficiency of spectrum and orbit utilization for the Broadcasting Satellite Service in the 12 GHz band for Region 2. It implements a constrained gradient-search procedure using an exponential objective function based on aggregate signal-to-noise ratio and an extended line search in the gradient direction. The procedure has been tested against a manually generated initial scenario and appears to work satisfactorily. In this test it was assumed that alternate channels use orthogonal polarizations at any one satellite location.

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I. INTRODUCTION

This report serves to document the work performed during the interim January 15, 1983 to July 15, 1983.

The status of the project on January 15, 1983 was primarily characterized by the decision to move toward a simultaneous optimization of system design variables through a nonlinear programming approach. The computer code that was being tested in January 1983 was designed to optimize orbit location only, subject to a single channel assigned to each service area. The channels were assumed to have the same frequency and to be co-polarized.

The work during the period from January to July was primarily directed toward extending the model, algorithm, and code to handle the more general case of multiple channels and polarization options and to prepare for testing the code with actual BSS scenarios. In particular, the following were accomplished:

1) Incorporation of multiple channels and polarizations in the model and code. The code was completely rewritten to minimize the burden of calculation.

2) Experimentation with the gradient search procedure to examine the impact of differential scaling of orbit position and frequency assignment.

3) Testing the code under the assumption that service areas be assigned channel frequencies in blocks, with alternating polarizations for the channels within each block.

4) Developing data bases for BSS scenarios including minimum ellipse and requirements files.

Section II of this report describes the nonlinear programming formulation of the problem. Section III discusses the gradient search procedure and our modifications of that procedure. An overview of the calculations involved in determining the partial derivatives of the gradient vector is given in Section IV. Section V presents an example, and Section VI reviews our recommendations for future work.

II. DESCRIPTION OF NONLINEAR PROGRAMMING FORMULATION

The goal of broadcast satellite system synthesis is to provide each service area with a specific number of "interference-free" channels. this criterion is met by insuring that acceptable (30 dB) C/I ratios exist at each of a specified set of test points. The design variables are the assignments of orbital positions to service areas and the assignments of frequency and polarization to each channel. The restrictions on the design variables are available bandwidth (12.1 GHz to 12.7 GHz) and allowable orbital positions (elevation angle and eclipse protection limit the range of orbital assignments).

The key to developing a nonlinear programming problem useful in broadcast satellite system synthesis is the specification of an objective function expressing the goal of providing acceptable C/I ratios for all test points. Since this problem will be solved by iterative techniques, the objective function must permit the C/I ratios of well-protected test points to be decreased whenever necessary to increase the C/I ratios of test points with insufficient protection. In other words, the impact on troublesome test points of a particular alteration of a given system synthesis must be given much higher weight than the impact on other test points that are not presenting problems. Futhermore, as much as possible, the objective function should be well-behaved.

We begin the description of the optimization model by defining the following index sets:

K - index set of service areas

J_k - index set of test points in service area k

N_k - index set of channels to be provided to service area k.

The objective function of the model can then be written as minimize

$$\Psi = \sum_{k \varepsilon K} \sum_{n \varepsilon N_k} \sum_{j \varepsilon J_k} \Psi_{knj}$$

where Ψ_{knj} represents an evaluation of the quality of channel n of service area k at test point j. Precisely, Ψ_{knj} is defined as

$$\Psi_{knj} = \exp(\alpha - \{P_{knknj} - 10\log_{10} \sum_{i\epsilon K/k} \sum_{m\epsilon N_i/n} 10^{P_{imknj}/10}\})$$

where α is a scaling factor (changed throughout the calculations as described later) and P_{imknj} is the power (in dB) received (after frequency filtering) at test point j of service area k by an antenna tuned to channel n; this power is received from the transmission of channel m by a satellite of service area i. If i = k and m = n, this is the desired signal. If i = k but m ≠ n, this is an interfering signal from another channel from the service area's own satellite. If i ≠ k, the interference comes from another service area's satellite.

The term in the braces is the C/I ratio (in dB) and ψ_{knj} increases as the C/I ratio becomes smaller. The exponential function weights the objective function contribution of channel-test points with lower C/I ratios more heavily than those with higher C/I ratios. Finally, α is set to a value equal to the lowest C/I ratio among all channel-test points at each trial solution. This insures that objective function terms and partial derivatives (to be discussed later) are calculated with the greatest numerical precision for troublesome test points. Figure 1 on the following page illustrates the relationship between Ψ_{knj}, α, and the C/I ratio of a particular channel-test point.

The minimization of this objective function is accomplished by finding those values of orbit position, frequency assignments to channels, and polarizations of channels that produce the smallest value of the function subject to constraints on allowable bandwidth (which

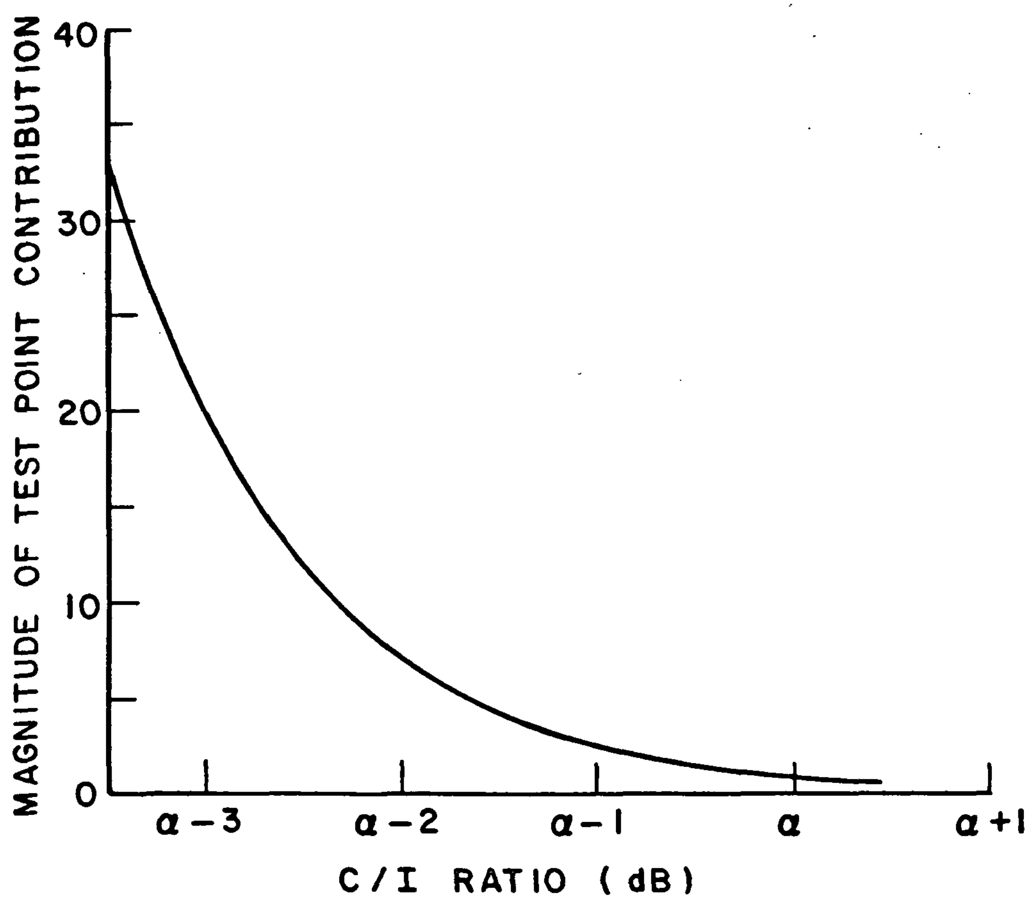

Figure 1. Objective function term vs. C/I ratio.

may be specified for each channel) and allowable orbit locations (which will be specified for each service area by eclipse protection and elevation angle minimums). Finding a guaranteed global minimum of such a complex function (the complexities are not fully evident here; they arise from angle calculations, frequency filter functions, antenna patterns, polarization effects, etc.) is an unlikely prospect at best. However, this approach seems capable of determining the feasibility of providing adequate C/I ratios given a set of system requirements.

III. CONSTRAINED GRADIENT SEARCH PROCEDURE

To describe the modifications we have made in the gradient search procedure, we begin by stating the algorithm. It should be kept in mind that this is actually a constrained search procedure due to upper and lower limits on frequency and orbit location. We assume the problem is in the following form:

$$\text{minimize} \quad f(x_1, \ldots, x_n)$$

$$\text{subject to} \quad L_j \leq x_j \leq U_j, \qquad j = 1, \ldots, n.$$

Then the procedure is as follows:

STEP 1: <u>INITIALIZATION</u>

Select trial values for $x_1, \ldots, x_n$ satisfying the bound constraints. Go to STEP 2.

STEP 2: <u>DIRECTION EVALUATION</u>

Calculate $\nabla f = (\partial f/\partial x_1, \ldots, \partial f/\partial x_n)$.

Then set

$$d_j = \begin{cases} -\partial f/\partial x_j \ ; & \partial f/\partial x_j > 0 \text{ and } x_j > L_j \\ -\partial f/\partial x_j \ ; & \partial f/\partial x_j < 0 \text{ and } x_j < U_j \\ 0 \ ; & \text{otherwise} \end{cases}$$

If d = 0, STOP, the current solution is a candidate for a constrained local minimum. Otherwise go to STEP 3.

STEP 3: <u>CONSTRAINED LINE SEARCH</u>

Calculate

$$\lambda_L = \underset{d_j<0}{\text{minimum}} \ \frac{L_j - x_j}{d_j}$$

$$\lambda_U = \underset{d_j>0}{\text{minimum}} \ \frac{U_j - x_j}{d_j}$$

$$\bar{\lambda} = \text{minimum} \ \{\lambda_L, \lambda_U\} \quad .$$

Determine the value λ^* that solves

$$\underset{0 < \lambda < \bar{\lambda}}{\text{minimize}} \quad f(x_1 + \lambda d_1, \ldots, x_n + \lambda d_n)$$

and go to STEP 4.

STEP 4: <u>NEW TRIAL SOLUTION</u>

Set $x_j = x_j + \lambda^* d_j \qquad j = 1, \ldots, n$

and go to STEP 2

Notice that the effect of this procedure is to solve a single multi-variable optimization problem by solving a sequence of single-variable optimization problems, where the single variable to be optimized in each problem is the distance to move in the search direction. If the function of the distance to be optimized in Step 3 is known to be well-behaved (e.g., it possesses a single local optimum in the search interval), very efficient methods are available for the solution. However, our problem is not so well-behaved and therefore Step 3 is not necessarily solved for an optimum distance. Rather, the objective function is evaluated at a predetermined number of equally spaced points in the interval $[0,\lambda]$ and the best value of the objective function determines the distance moved in the iteration.

Another alteration in the procedure described is to define two search intervals, one based on satellite orbit limits and the other based on channel frequency limits. This modification has worked well as it allows for significant frequency changes earlier in the sequence of iterations than would be the case for a single search interval based on limits for both position and frequency.

IV. GRADIENT CALCULATION

The heart of each of the iterative solution procedures discussed in the previous section is the calculation of the gradient vector, i.e., the vector of partial derivatives of the objective function with respect to the design variables. This represents an extremely complex calculation for the current problem. This is particularly true for the case of partial derivatives with respect to orbit locations as they require extensive angular calculations.

To indicate the complexity of the gradient calculation, some of the higher level computations in the chain of computations leading to the partial derivatives of the objective function with respect to orbit location and channel frequency are given here. We begin with $\partial\Psi/\partial o_\ell$ where o_ℓ is the orbit location of the satellite of service area ℓ:

$$\frac{\partial\Psi}{\partial o_\ell} = \sum_{k\varepsilon K} \sum_{j\varepsilon J_k} \sum_{n\varepsilon N_k} \{\Psi_{knj} \cdot (\sum_{i\varepsilon K/k} \sum_{m\varepsilon N_i} 10^{P_{imknj}/10})^{-1} \cdot (\sum_{i\varepsilon K/k} \sum_{m\varepsilon N_i} 10^{P_{imknj}/10} \frac{\partial P_{imknj}}{\partial o_\ell})\} \quad .$$

In computing the above partial derivative, it is obviously useful to note that

$$\frac{\partial P_{imknj}}{\partial o_\ell} = 0 \quad \text{if } \ell \neq k \text{ and } \ell \neq i$$

and

$$\frac{\partial P_{imknj}}{\partial o_\ell}$$ is independent of m and n.

The corresponding expression for $\partial\Psi/\partial f_{\ell h}$ where $f_{\ell h}$ is the frequency of channel h of service area ℓ is given by:

$$\frac{\partial \Psi}{\partial f_{\ell h}} = \sum_{k \varepsilon K} \sum_{j \varepsilon J_k} \sum_{n \varepsilon N_k} \{\Psi_{knj} \cdot \left(\sum_{i \varepsilon K/k} \sum_{m \varepsilon N_i} 10^{P_{imknj}/10} \right)^{-1}$$

$$\cdot \left(\sum_{i \varepsilon K/k} \sum_{m \varepsilon N_i} 10^{P_{imknj}/10} \frac{\partial P_{imknj}}{\partial f_{\ell h}} \right)\} \quad .$$

Here we note that

$$\frac{\partial P_{imknj}}{\partial f_{\ell h}} = 0 \text{ if } \ell \notin N_i \text{ and } \ell \notin N_k \quad .$$

To evaluate the partial derivatives of P_{imknj}, we use the well-known relation

$$P_{imknj} = P^T_{im} + G^T_{im} + D^T_{ikj} \left(\frac{\phi^T_{ikj}}{\phi^0_{ikj}} \right) + G^R_{km} + D^R_{ikj} \left(\frac{\phi^R_{ikj}}{\phi^0_{jk}} \right)$$

$$+ F^f_{mn} - 20\log_{10} f_m - 20\log_{10} R_{ikj} + (\text{constant})$$

where we have

P^T_{im} - power transmitted in channel m of service area i

G^T_{im} - transmitter gain for channel m of service area i

D^T_{ikj} - transmitting antenna directivity factor between test point j of service area k and the beam direction to service area i

G_k^R - receiver gain for service area k

D_{ikj}^R - receiving antenna directivity factor between the location of the satellite transmitting to test point j of service area k and the satellite location of service area i

F_{mn}^f - frequency discrimination between channels m and n

f_m - transmitted frequency

R_{ikj} - distance from satellite for service area i to test point in service area k

ϕ_{ikj}^T - angle between the axis of beam transmitted to service area i and a line from the satellite of service area i to test point j of service area k

ϕ_{ikj}^0 - angular equivalent of 3 dB power reduction in the transmitting antenna pattern of the satellite transmitting to service area i in the plane formed by the beam boresight and the line from the satellite to test point j of service area k.

ϕ_{ikj}^R - angle between the satellites of service areas i and k as seen from test point j of service area k

ϕ_{kj}^0 - angular equivalent of 3 dB power reduction in the receiving antenna pattern at test site j of service area k.

Keeping in mind which terms in the above expression vary with orbit locations and frequencies, we can now write the following partial derivatives:

$$\frac{\partial P_{imknj}}{\partial o_i} = \frac{\partial}{\partial o_i}\left[D^T_{ikj}\left(\frac{\phi^T_{ikj}}{\phi^0_{ikj}} \right)\right] + \frac{\partial}{\partial o_i}\left[D^R_{ikj}\left(\frac{\phi^R_{ikj}}{\phi^0_{kj}} \right)\right]$$

$$- 20\log_{10} e(R_{ikj})^{-1} \frac{\partial}{\partial o_i}(R_{ikj})$$

$$\frac{\partial P_{imknj}}{\partial o_k} = \frac{\partial}{\partial o_k}\left[D^R_{ikj}\left(\frac{\phi^R_{ikj}}{\phi^0_{kj}} \right)\right]$$

$$\frac{\partial P_{imknj}}{\partial f_{im}} = \frac{\partial F^f_{mn}}{\partial f_{im}} - 20\log_{10} e/f_m$$

$$\frac{\partial P_{imknj}}{\partial f_{kn}} = \frac{\partial F^f_{mn}}{\partial f_{kn}} \quad .$$

At this point in the chain of calculations it is apparent that the remaining partial derivative calculations depend on the exact forms assumed for the antenna patterns and the frequency filter functions. It should be noted that the frequency partial derivatives are much simpler than the orbit location partial derivatives, particularly those involving transmitting antennas. The partials involving transmission require lengthy angular calculations involving the projection of the elliptical beam from the satellite's coordinate system into the earth's coordinate system. The calculation of these partial derivatives will not be detailed here.

V. EXAMPLE OF PROCEDURE

The following problem is intended to illustrate the nature of the interaction between the objective function (primarily its concentration on poorly protected test point-frequency pairs) and the iterative search procedure in attempting to identify an acceptable solution. The problem is based on the six service areas as illustrated (along with the test point locations) in Figure 2. Table I provides all the relevant information concerning the parameters of the problem.

This example is based on the assumption that the channel frequencies for any service area will be assigned in a regular pattern with fixed channel spacing (in this example, 13 MHz is the spacing) and alternating polarizations. The reasons for this assumption are twofold. First, this arrangement of channel frequencies allows flexibility for moving toward high-definition TV. Second, it provides very considerable computational benefits. To do otherwise would require model decision variables for each channel of each service area. With the regularity assumption, we need only one frequency to "locate" the pattern. This results in a factor of model size reduction of about 25 to 1.

One may note in Table II that the initial solution has problem test point-frequency pairs for Argentina, Bolivia, and Paraguay. The lowest C/I ratios occur for frequency 1 in Paraguay.

Table III indicates substantial progress has been made in the first iteration. The most troublesome test point-frequency pairs in the initial solution have been improved by moving Argentina and Paraguay apart in both satellite location and frequency. At this point, the lowest C/I ratios occur for both frequencies in Bolivia.

Table IV indicates that the second iteration made good improvement in the solution by moving Bolivia and Paraguay apart in both satellite location and frequency. Now the lowest C/I ratios occur again for frequency 1 of Paraguay.

Table V indicates that moving Argentina and Paraguay apart in satellite location and Paraguay and Peru apart in frequency has again improved the solution. Furthermore, all C/I ratios are reasonably good; the smallest is 29.16 dB. Subsequent iterations make negligible improvement in the solution, as shown by Table VI.

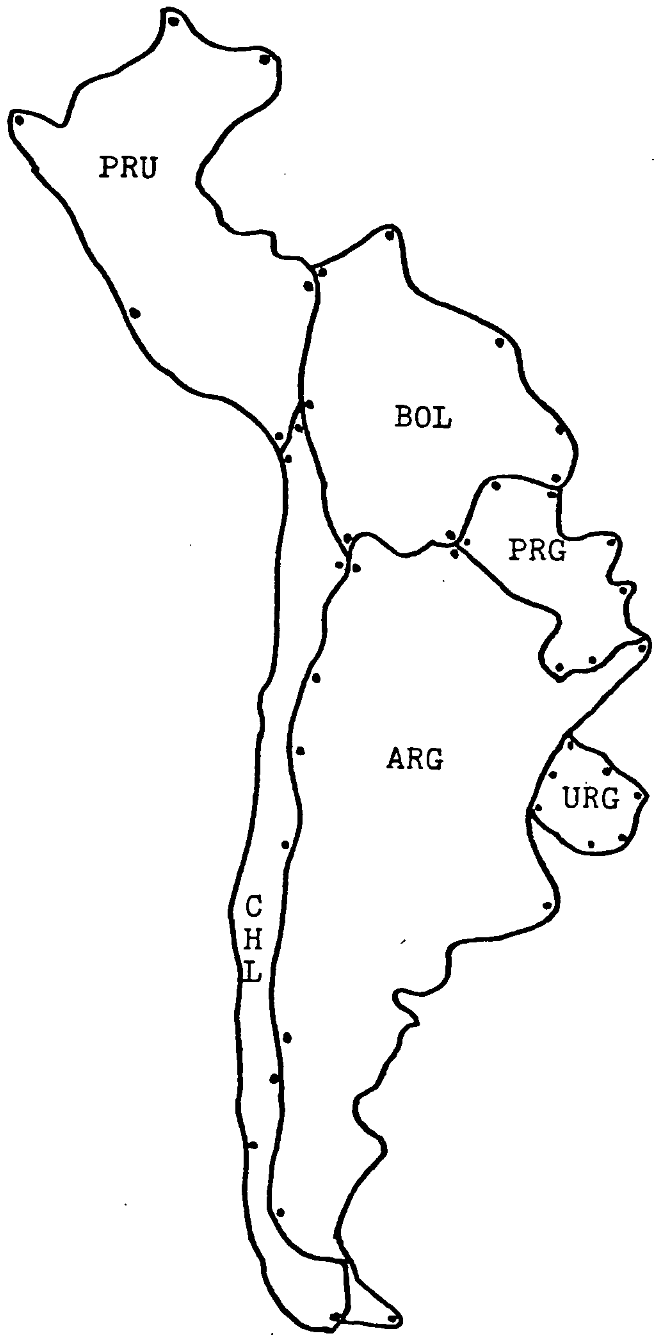

Figure 2. Service areas and test points.

TABLE I

PROBLEM PARAMETERS

AVAILABLE ORBIT SPECTRUM	0.0	-180.00
AVAILABLE BANDWIDTH	12500.00	12700.00
CHANNEL SPACING	13.00	
CHANNEL WIDTH	12.00	
CHANNEL SPACING TO NEGLECT	52.00	
ORBIT SPACING TO NEGLECT	20.00	
CARSONS BANDWIDTH	25.00	
STEP SIZE USED IN PHI0 DERIVATIVE	0.0500	

SERVICE AREA SPECIFICATIONS

NAME	CODE	CHANNELS REQD	LIMITS ON SAT.LOC EAST	WEST
ARGENTINA	ARG	3	-75.0	-110.0
BOLIVIA	BOL	2	-75.0	-110.0
CHILE	CHL	2	-75.0	-110.0
PARAGUAY	PRG	4	-75.0	-110.0
PERU	PRU	3	-75.0	-110.0
URUGUAY	URG	3	-75.0	-110.0

SERVICE AREA SPECIFICATIONS

NAME	CODE	CHANNELS REQD	LIMITS ON FREQUENCY LOW	HIGH	INITIAL ASSIGNMENTS SAT.LOC	FREQ.	POLAR.
ARGENTINA	ARG	3	12500.0	12600.0	-80.0	12500.0	1
BOLIVIA	BOL	2	12500.0	12600.0	-90.0	12505.0	1
CHILE	CHL	2	12500.0	12600.0	-100.0	12515.0	1
PARAGUAY	PRG	4	12500.0	12600.0	-85.0	12520.0	1
PERU	PRU	3	12500.0	12600.0	-105.0	12535.0	1
URUGUAY	URG	3	12500.0	12600.0	-95.0	12535.0	1

TABLE I

(CONTINUED)

SERVICE AREA ARGENTINA CODE ARG NUMBER OF TEST POINTS = 9

#	LAT.	LON.
1	-37.000	-56.500
2	-26.200	-53.600
3	-55.000	-66.000
4	-22.000	-63.000
5	-28.000	-69.200
6	-32.000	-70.400
7	-22.000	-66.000
8	-43.000	-72.200
9	-50.000	-73.500

SERVICE AREA BOLIVIA CODE BOL NUMBER OF TEST POINTS = 8

#	LAT.	LON.
1	-9.600	-65.500
2	-11.000	-69.500
3	-17.500	-69.500
4	-23.000	-68.000
5	-23.000	-64.500
6	-13.500	-62.000
7	-20.000	-57.800
8	-16.400	-58.000

SERVICE AREA CHILE CODE CHL NUMBER OF TEST POINTS = 7

#	LAT.	LON.
1	-56.000	-69.000
2	-46.000	-76.000
3	-44.000	-71.000
4	-34.000	-72.000
5	-23.000	-66.500
6	-17.600	-70.000
7	-18.500	-71.500

TABLE I

(CONTINUED)

SERVICE AREA PARAGUAY CODE PRG NUMBER OF TEST POINTS = 7

#	LAT.	LON.
1	-22.200	-63.000
2	-19.800	-62.000
3	-19.300	-59.000
4	-22.300	-55.600
5	-24.000	-54.200
6	-27.500	-55.500
7	-27.600	-58.800

SERVICE AREA PERU CODE PRU NUMBER OF TEST POINTS = 6

#	LAT.	LON.
1	-18.500	-70.500
2	-12.500	-68.600
3	-4.100	-69.800
4	0.0	-75.500
5	-5.000	-81.200
6	-12.000	-77.000

SERVICE AREA URUGUAY CODE URG NUMBER OF TEST POINTS = 7

#	LAT.	LON.
1	-32.800	-53.000
2	-34.500	-53.700
3	-35.000	-55.500
4	-34.000	-58.500
5	-31.400	-58.000
6	-30.100	-51.000
7	-31.000	-55.500

TABLE II

ITERATION 1

OBJECTIVE FUNCTION 0.3031691918D-04 ZALPHA 10.00000

AREA CODE	PARTIAL DERIVATIVES W.R.T SAT.LOCATION	FREQUENCY
ARG	-0.32758D-02	0.50116D-06
BOL	0.17671D-03	0.22565D-05
CHL	0.10436D-03	-0.73839D-06
PRG	0.29386D-02	-0.16129D-05
PRU	0.68790D-07	-0.25416D-09
URG	0.18018D-04	-0.42713D-06

ARGENTINA SAT.LOC = -80.00 BASE FREQ. = 12500.00

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	37.05	36.40	35.42	32.33	33.07	33.85	31.78	34.56	33.52
FREQ 2	37.01	36.36	35.39	32.31	33.05	33.83	31.77	34.55	33.50
FREQ 3	34.51	24.41	37.78	24.41	34.05	37.62	26.81	38.29	37.09

BOLIVIA SAT.LOC = -90.00 BASE FREQ. = 12505.00

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	26.82	30.27	30.79	29.10	28.00	27.09	24.85	24.40
FREQ 2	26.84	30.28	30.80	29.11	28.01	27.11	24.86	24.42

CHILE SAT.LOC = -100.00 BASE FREQ. = 12515.00

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	41.24	39.93	38.81	36.94	33.95	34.29	34.58
FREQ 2	42.11	40.53	39.68	37.62	34.28	34.57	34.87

TABLE II

(CONTINUED)

PARAGUAY SAT.LOC = -85.00 BASE FREQ. = 12520.00

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	22.51	22.52	22.74	23.18	22.80	22.11	21.91
FREQ 2	31.48	31.44	32.08	32.93	32.67	31.96	31.60
FREQ 3	35.22	35.71	36.07	35.77	35.08	33.97	33.89
FREQ 4	37.32	37.95	38.38	37.87	37.10	35.89	35.83

PERU SAT.LOC = -105.00 BASE FREQ. = 12535.00

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	30.79	36.43	41.53	41.11	41.47	37.97
FREQ 2	36.57	40.40	41.69	41.24	41.71	41.25
FREQ 3	39.99	46.53	64.61	68.26	62.46	48.60

URUGUAY SAT.LOC = -95.00 BASE FREQ. = 12535.00

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	35.85	36.18	36.22	36.08	35.46	35.21	35.26
FREQ 2	39.13	40.04	40.34	40.16	38.46	37.82	37.95
FREQ 3	48.54	50.62	51.52	50.99	47.26	46.28	46.42

TABLE III

ITERATION 2

OBJECTIVE FUNCTION 0.3397996478D-01 ZALPHA 21.91364

AREA CODE	PARTIAL DERIVATIVES W.R.T SAT.LOCATION	FREQUENCY
ARG	-0.81709D+00	0.43654D-04
BOL	0.24669D+01	0.15958D-01
CHL	0.41103D+00	-0.34531D-02
PRG	-0.22977D+01	-0.98564D-02
PRU	0.41785D-01	-0.20053D-03
URG	0.12738D+00	-0.25149D-02

ARGENTINA SAT.LOC = -77.00 BASE FREQ. = 12500.00

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	40.22	40.15	36.72	35.37	35.83	36.57	34.53	36.33	34.07
FREQ 2	40.20	40.13	36.71	35.36	35.82	36.56	34.52	36.33	34.07
FREQ 3	38.75	31.51	42.05	31.75	38.63	41.60	33.17	42.06	40.83

BOLIVIA SAT.LOC = -90.16 BASE FREQ. = 12502.00

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	30.80	34.83	34.74	32.31	30.63	30.35	27.43	27.28
FREQ 2	30.71	34.73	34.67	32.26	30.59	30.29	27.39	27.23

CHILE SAT.LOC = -100.10 BASE FREQ. = 12515.98

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	45.88	44.45	43.17	41.19	34.65	36.54	37.34
FREQ 2	45.81	44.41	43.13	41.13	34.62	36.51	37.30

TABLE III

(CONTINUED)

PARAGUAY		SAT.LOC = -87.69			BASE FREQ. =		12522.14
	C/I RATIOS FOR EACH TEST POINT - FREQUENCY						
FREQ 1	28.05	28.05	28.35	28.78	28.61	28.09	27.82
FREQ 2	30.28	30.23	30.69	31.26	31.12	30.64	30.37
FREQ 3	33.92	34.41	34.75	34.30	33.78	32.86	32.78
FREQ 4	36.42	36.93	37.26	36.79	36.26	35.33	35.25

PERU		SAT.LOC = -105.00			BASE FREQ. =	12535.00
	C/I RATIOS FOR EACH TEST POINT - FREQUENCY					
FREQ 1	30.25	35.61	39.92	39.52	39.93	37.15
FREQ 2	30.26	35.63	39.97	39.58	39.99	37.18
FREQ 3	31.20	37.70	55.82	58.51	54.49	39.87

URUGUAY		SAT.LOC = -95.02			BASE FREQ. =		12535.57
	C/I RATIOS FOR EACH TEST POINT - FREQUENCY						
FREQ 1	34.91	35.78	36.11	35.95	34.43	33.74	34.00
FREQ 2	35.97	37.16	37.71	37.55	35.43	34.51	34.85
FREQ 3	40.82	42.61	43.53	43.24	40.03	38.84	39.28

TABLE IV

ITERATION 3

OBJECTIVE FUNCTION   0.2716199634D+01   ZALPHA 27.22814

AREA CODE	PARTIAL DERIVATIVES W.R.T SAT.LOCATION	FREQUENCY
ARG	-0.10549D+03	0.17649D-01
BOL	0.37528D+01	0.16110D+00
CHL	0.29832D+02	-0.78255D-01
PRG	0.49006D+02	0.23822D+00
PRU	0.10182D+02	-0.44683D-01
URG	0.73985D+01	-0.29592D+00

ARGENTINA   SAT.LOC = -76.40   BASE FREQ. = 12500.00

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	42.32	41.99	38.78	37.24	37.82	38.61	36.39	38.36	36.05
FREQ 2	42.29	41.96	38.77	37.23	37.81	38.60	36.38	38.36	36.04
FREQ 3	40.02	31.04	42.40	31.01	39.63	42.34	33.09	42.45	41.10

BOLIVIA   SAT.LOC = -91.97   BASE FREQ. = 12501.40

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	32.06	36.11	36.66	34.45	33.45	32.43	30.54	29.88
FREQ 2	32.02	36.07	36.63	34.43	33.43	32.40	30.52	29.85

CHILE   SAT.LOC = -100.40   BASE FREQ. = 12516.11

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	45.87	44.38	43.17	41.18	36.13	37.17	37.69
FREQ 2	45.84	44.36	43.16	41.14	36.10	37.14	37.65

TABLE IV

(CONTINUED)

PARAGUAY		SAT.LOC = -86.00			BASE FREQ. =		12522.51	
	C/I RATIOS FOR EACH TEST POINT - FREQUENCY							
FREQ 1	28.55	28.61	28.74	29.07	28.68	27.92	27.71	
FREQ 2	32.78	32.75	32.92	33.29	32.89	32.25	32.16	
FREQ 3	35.91	36.38	36.77	36.47	35.78	34.63	34.54	
FREQ 4	38.81	39.32	39.71	39.36	38.66	37.49	37.40	

PERU		SAT.LOC = -105.03			BASE FREQ. =		12535.01
	C/I RATIOS FOR EACH TEST POINT - FREQUENCY						
FREQ 1	30.09	35.35	39.19	38.75	39.17	36.74	
FREQ 2	30.10	35.38	39.25	38.81	39.22	36.77	
FREQ 3	31.16	37.71	56.91	59.42	54.50	39.82	

URUGUAY		SAT.LOC = -95.11			BASE FREQ. =		12535.66	
	C/I RATIOS FOR EACH TEST POINT - FREQUENCY							
FREQ 1	37.17	37.77	37.90	37.71	36.61	36.12	36.27	
FREQ 2	38.84	39.84	40.18	39.99	38.16	37.33	37.60	
FREQ 3	44.53	46.83	47.85	47.25	43.21	41.89	42.31	

TABLE V

ITERATION 4

OBJECTIVE FUNCTION 0.1567251204D+01 ZALPHA 27.70884

AREA CODE	PARTIAL DERIVATIVES W.R.T SAT.LOCATION	FREQUENCY
ARG	-0.32280D+02	0.10464D-01
BOL	0.44861D+01	0.75279D-01
CHL	0.98336D+01	0.48925D-01
PRG	-0.14487D+02	-0.36251D+00
PRU	0.20326D+02	-0.81606D-01
URG	0.94397D+01	0.30836D+00

ARGENTINA SAT.LOC = -75.14 BASE FREQ. = 12500.00

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	43.17	42.71	39.34	37.99	38.57	39.37	37.10	38.94	36.45
FREQ 2	43.13	42.67	39.33	37.98	38.55	39.35	37.08	38.94	36.44
FREQ 3	46.04	33.24	55.54	33.09	44.10	52.37	35.24	57.95	53.86

BOLIVIA SAT.LOC = -92.02 BASE FREQ. = 12500.14

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	33.79	38.33	38.61	35.95	34.70	33.94	31.70	31.22
FREQ 2	33.74	38.26	38.55	35.91	34.67	33.90	31.67	31.18

CHILE SAT.LOC = -100.75 BASE FREQ. = 12516.72

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	48.63	47.21	46.04	44.10	36.97	38.18	38.88
FREQ 2	48.72	47.28	46.09	44.07	36.94	38.14	38.84

TABLE V

(CONTINUED)

PARAGUAY SAT.LOC = -86.59 BASE FREQ. = 12520.65

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	29.93	29.94	30.04	30.43	30.08	29.38	29.16
FREQ 2	33.29	33.16	33.31	33.82	33.51	32.98	32.85
FREQ 3	32.08	32.63	33.01	32.59	31.89	30.70	30.60
FREQ 4	32.38	32.95	33.33	32.90	32.18	30.98	30.89

PERU SAT.LOC = -105.15 BASE FREQ. = 12535.36

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	29.90	34.96	38.28	37.82	38.27	36.26
FREQ 2	29.91	34.98	38.32	37.88	38.31	36.29
FREQ 3	31.20	37.75	56.64	59.46	54.42	39.84

URUGUAY SAT.LOC = -95.20 BASE FREQ. = 12537.98

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	37.03	38.81	39.56	39.19	36.01	34.97	35.21
FREQ 2	37.04	38.83	39.59	39.21	36.02	34.98	35.22
FREQ 3	48.47	50.87	51.87	51.19	47.03	45.28	46.13

TABLE VI

ITERATION 5

OBJECTIVE FUNCTION 0.5432355852D+01 ZALPHA 29.15625

AREA CODE	PARTIAL DERIVATIVES W.R.T SAT.LOCATION	FREQUENCY
ARG	-0.12939D+03	0.30588D-01
BOL	0.13957D+02	0.24662D+00
CHL	0.44528D+02	0.16242D+00
PRG	0.18544D+01	-0.16853D+00
PRU	0.73877D+02	-0.29113D+00
URG	-0.15444D+02	0.16259D-01

ARGENTINA SAT.LOC = -75.01 BASE FREQ. = 12500.00

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	43.27	42.87	39.40	38.10	38.65	39.45	37.19	39.00	36.49
FREQ 2	43.24	42.84	39.40	38.09	38.64	39.43	37.18	39.00	36.49
FREQ 3	46.13	33.32	55.63	33.16	44.19	52.52	35.30	58.06	53.94

BOLIVIA SAT.LOC = -92.04 BASE FREQ. = 12500.01

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	33.91	38.48	38.77	36.10	34.90	34.08	31.93	31.40
FREQ 2	33.86	38.42	38.72	36.07	34.87	34.04	31.90	31.36

CHILE SAT.LOC = -100.79 BASE FREQ. = 12516.64

C/I RATIOS FOR EACH TEST POINT - FREQUENCY

FREQ 1	48.42	47.02	45.77	43.84	37.00	38.34	39.03
FREQ 2	48.47	47.06	45.80	43.80	36.97	38.30	38.99

TABLE VI

(CONTINUED)

PARAGUAY	SAT.LOC = -86.53				BASE FREQ. =		12521.26
	C/I RATIOS FOR EACH TEST POINT - FREQUENCY						
FREQ 1	29.98	29.99	30.09	30.46	30.10	29.40	29.18
FREQ 2	33.30	33.19	33.33	33.80	33.46	32.92	32.80
FREQ 3	33.50	34.03	34.41	34.03	33.33	32.15	32.05
FREQ 4	34.07	34.63	35.01	34.59	33.88	32.69	32.59

PERU	SAT.LOC = -105.23				BASE FREQ. =	12535.49
	C/I RATIOS FOR EACH TEST POINT - FREQUENCY					
FREQ 1	30.04	35.18	38.68	38.23	38.67	36.51
FREQ 2	30.06	35.20	38.73	38.29	38.72	36.54
FREQ 3	31.26	37.80	56.80	59.52	54.55	39.90

URUGUAY	SAT.LOC = -95.24				BASE FREQ. =		12537.46
	C/I RATIOS FOR EACH TEST POINT - FREQUENCY						
FREQ 1	38.04	39.63	40.27	39.94	37.09	36.09	36.35
FREQ 2	38.06	39.66	40.30	39.97	37.11	36.10	36.36
FREQ 3	47.48	49.84	50.85	50.21	46.09	44.46	45.19

VI. PROSPECTS FOR SUCCESS AND PLANS FOR FUTURE WORK

The computational experiments run to date have been on small problems. The results have been very encouraging. In particular, we can state the following:

- The gradient calculation is accurate and efficiently coded.
- The procedure always makes reasonable decisions that result in solution improvements.
- The computation times are reasonable. The CPU time required for the previous example was less than 1 second per iteration. The growth in CPU time should not be faster than linear with respect to the number of service areas.

There are, however, potential technical problems with our approach that may become apparent with larger problems. They include the following:

- Lack of convergence or slow convergence to local optima.
- Local optima may vary substantially in the quality of the C/I ratios. There is no obvious procedure for heading toward "better" local optima.

Our plans to address these issues are the following:

- Solution of full size problem beginning with syntheses from FCC files and RARC 83.
- Experimentation with modifications of gradient search including both standard modified gradient procedures and problem-specific fine tuning of the gradient procedure.