A UNITED STATES
DEPARTMENT OF
COMMERCE
PUBLICATION

ESSA Technical Report ERL 158-ITS 101

U.S. DEPARTMENT OF COMMERCE
Environmental Science Services Administration
Research Laboratories

System Design Considerations for the Development of the IGOSS Ocean Data HF Transmission System

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BOULDER, COLO.
MARCH 1970

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For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402
Price 40 cents.

FOREWORD

The work described in this report was done at the request of Commandant (FS-1), U. S. Coast Guard. It was funded under Interdepartmental Purchase Request No. Z-70099-9-91574, dated 16 September 1968, and monitored by LCDR Marshall E. Gilbert, USCG.

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SYSTEM DESIGN CONSIDERATIONS FOR THE DEVELOPMENT OF THE IGOSS OCEAN DATA HF TRANSMISSION SYSTEM

Thijs de Haas and Dale N. Hatfield

System design questions associated with the development of an ocean data HF transmission system for the Integrated Global Ocean Station System (IGOSS) and the National Data Buoy Systems are considered. These include (1) development of a computer model of the data transmission system for design and operational coordination purposes, (2) formulation of the bandwidth-time allocation problem on a formal mathematical optimization basis, (3) review of the advantages and disadvantages of two methods of initiating data readout from remote platforms, and (4) evaluation of two basic data transmission methods. Recommendations for future work are made.

Key words: HF transmission system, Integrated Global Ocean Station System (IGOSS), National Data Buoy Systems, oceanographic data transmission.

1. INTRODUCTION

The Integrated Global Ocean Station System (IGOSS) will consist of a large number of platforms, such as moored and drifting unmanned buoys, instrumented merchant ships, research vessels, etc., that will gather certain meteorological and oceanographic data, collectively called ocean data. These data must then be transmitted to selected shore stations from which they can be distributed to appropriate users.

The 1967 World Administrative Radio Conference (WARC) allocated certain HF radio bands specifically for the transmission of ocean data and invited the Intergovernmental Oceanographic Commission (IOC) and

World Meteorological Organization (WMO), in consultation with the International Frequency Registration Board (IFRB), to develop a co-ordinated plan for the use of these frequencies (Resolution No. MAR 20, WARC 1967). The task of developing this plan led to the formation of a Joint WMO/IOC Group of Experts on Telecommunications, which has held two sessions (Geneva, September 1968; Paris, January 1969).[1]

The U.S. Coast Guard has been assigned national responsibility for providing support towards the development of IGOSS and for the development of the National Data Buoy Systems, appropriate parts of which will also form part of IGOSS. Under contract with the U.S. Coast Guard, ESSA's Institute for Telecommunication Sciences (ITS) conducts studies pertaining to the design of the HF communication system.

The particular subjects discussed in this report are:

(a) Computer modeling of the system.

(b) Assignment methods (data read out programming).

(c) Methods of initiating data read out.

(d) Data transmission methods (utilization of available time-bandwidth).

Although these subjects are treated in the individual sections of the report, interrelations exist between them, as will become apparent.

Many of the persons participating in the development of the IGOSS are not specialists in the field of communications. In order to increase the usefulness of this report to all those interested in these subjects, we have tried to present the material in as nontechnical form as possible.

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[1] Mr. T. de Haas is a member of the Joint WMO/IOC Group of Experts on Telecommunications.

2. THE CONCEPTUAL PLAN FOR COMPUTER MODELING

2.1 Purpose of Model

Planning of the data collection system must allow for an orderly development of the IGOSS on a long-term basis. At the same time the fewest possible constraints should be imposed on the operation of the system during the interim period, when the number of platforms may be only a fraction of the total number envisaged.

The many platforms, the changes in propagation conditions due to diurnal, seasonal, and solar activity variations, and the limited time available for the data collection require that the individual platform transmissions be closely coordinated. Such coordination can be achieved by means of a computer model of the data collection system that computes and issues schedules for the data transmissions from all platforms.

Since, ultimately, a large number of the platforms will be non-stationary, e.g. ships, their geographical distribution may vary considerably with time and the model must therefore be able to allow for relatively frequent changes in transmission schedules. The model must also be able to accept externally imposed requirements, such as special emphasis on specific ocean areas during hurricanes and other natural disturbances.

2.2 Basic Premises

The Joint WMO/IOC Group of Experts on Telecommunications in 1969 agreed on the following tentative principles:

(a) The preferred method of data collection should be by interrogation.

(b) Worldwide interrogation should be essentially time-synchronous to prevent the relatively strong interrogating signals from interfering with data transmission.

(c) Designation of interrogating station for any given platform at any specific time should be based on technical considerations, i.e., propagation conditions, interference control, etc.

(d) The platform should be functionally controlled during non-synoptic data periods (precludes data on system status at synoptic period).

(e) Technical standardization should include, and be limited to, parameters necessary to ensure compatibility in the overall system.

(f) Operating schedules should be issued by an international coordinating body.

(g) The system should include both moored and moving platforms.

In addition to these principles, the following assumptions have been postulated:[2]

(a) The global ocean surface will be divided into several areas (not necessarily uniform in size), and for purposes of data collection each area will be considered a single entity, e.g., in calculating propagation path conditions, all platforms in a specific area will be considered a single location.

(b) Each specific area will be assigned a maximum number of platforms, e.g., when by chance an unusually large number of ships are simultaneously in the same area, not all ships would be interrogated.

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[2] The assignments under assumptions (a), (b), and (c) are not built-in unchangeable numbers. Although the initial design will have to be based on possible, rather arbitrary choices, the assignments made under (b) and (c) are, within limits, thought of as variable on a short time scale of, say, days or hours. Since a change in (a) will entail a substantial change in the model, (a) is not considered variable in an operational sense.

(c) For data collection, priorities will be assigned to platforms, with moored platforms generally given highest priority, while priority assignments to moving platforms may vary according to geographical position.

(d) Simultaneously interrogated platforms, reporting to the same shore station in the same frequency band, should be chosen so that they will produce nearly equal signal strengths in the shore station receiver.

(e) Moored platforms will have permanent identification codes, while moving platforms may be required to change identification code depending on their geographical location at a given time.

2.3 Organization and Plan

Basically, the model will perform the following operations for each synoptic time period:

(a) For each shore station location, the predicted signal strength for transmissions originating from each area will be calculated for each frequency band.

(b) Based on the results of (a) above, the optimum propagation path, the minimum required platform power, and the best frequency, as well as the two next best frequencies, will be determined for each area.

(c) Based on the results of (a) and (b) above, the interrogation schedule for platforms assigned the highest priority will be calculated first, then the schedule for platforms with the next highest priority, etc.

In addition to meeting the necessity for calculating usable radio paths, operation (a) also provides the basis for keeping mutual interference below the harmful level. The calculation under (a) must be performed for each synoptic time of day, for each season, and for different average sunspot numbers. It can be incorporated in the main program as a subroutine, or a "library" can be precomputed, with the appropriate "section" used for each run of the main program. The latter procedure may be more efficient, especially when the model is to be used for trade-off studies.

If platform priorities can be expressed as relative weights, operation (c) can be performed in a type of iterative sequence, to yield a maximized system output regardless of platform distribution. Assignment methods in terms of overall system efficiency are discussed in section 3.

2.4 Interim Operation

The principal difference for the immediate future is that the number of platforms will be much smaller than that envisaged for the full system and that only a limited number of shore stations may be available at first. Operationally, this has the following consequences:

(a) At least for the first few years, most, if not all, platforms can be assigned a unique channel/time combination for interrogation, making mutual interference problems minimal or nonexistent.

(b) The computations for preparation of interrogation schedules will initially be relatively simple, which will make it possible to gradually phase in the computer modeling system. This, in turn, will allow operational experience to be accummulated, which can be used to improve (or correct) the program.

(c) For some parts of the oceans, platforms may be so few as to make the projected shore stations undesirable until later, and these platforms may therefore have to be interrogated over circuits providing a lower grade of service than intended.

(d) The light loading of the system will, however, permit reinterrogation at the end of the regularly scheduled period of those platforms for which sufficiently error-free data have not been obtained, although buoy power limitations will limit the number of such reinterrogations.

2.5 Development of the Model

In the development of the model, the following steps are necessary:

(a) Assumption of an initial distribution of approximate shore station locations that will provide worldwide coverage. Figure 1 shows a possible distribution chosen on the basis of coverage of most of the global ocean area within one-hop propagation distances.

(b) Computation of propagation profiles for a number of radials from representative shore station locations, for various propagation conditions.

(c) Determination of area sizes for different geographical locations that, from a propagation point of view, can be regarded as single transmission points and division of the surface to be covered by the system in such areas. Preliminary calculations have shown that an area size of 300 by 300 km is suitable for most of the oceans.

(d) Development of the basic program and check of the system concept based on known requirements, augmented if necessary by assumptions regarding platform density.

(e) Development of a detailed program.

(f) Determination of total system capacity and limitations, including trade-off studies as required.

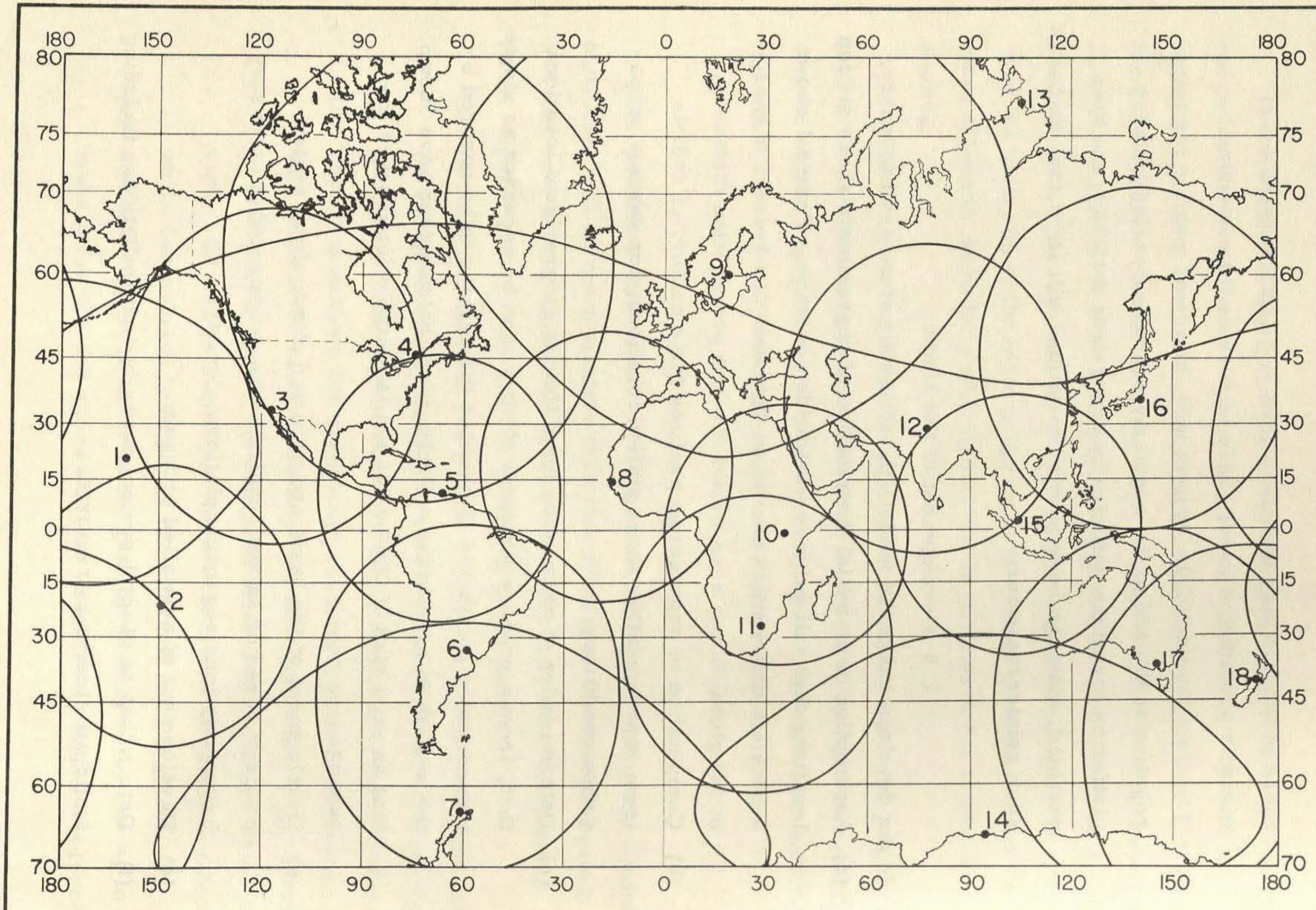

Figure 1. A possible distribution of shore stations.

3. ASSIGNMENT TECHNIQUES

3.1 Background

The purpose of this section is to more precisely identify the IGOSS scheduling problem and, at the same time, lay the groundwork for future development and adoption of "optimal" scheduling techniques.

3.2 Problem

The scheduling of platforms for a particular shore station, frequency, channel, and time slot combination is analogous to the "assignment problem," which has been dealt with extensively in the operations research literature. For an elementary treatment see Churchman et al. (1957). To formulate the IGOSS scheduling problem in these terms, consider a variable $X_{ijk\ell m}$, where

$1 \le i \le I$, i = shore station number in a total of I,

$1 \le j \le J$, j = frequency number in a total of J,

$1 \le k \le K$, k = channel number in a total of K,

$1 \le \ell \le L$, ℓ = time slot number in a total of L such times in the interrogation period, and

$1 \le m \le M$, m = platform number in a total of M.

Let $X_{ijk\ell m} = 1$ mean that shore station i is assigned to receive the data from platform m on frequency j and channel k in time slot ℓ. Conversely, let $X_{ijk\ell m} = 0$ indicate that shore station i is <u>not</u> assigned to platform m on frequency j and channel k in time slot ℓ. The $X_{ijk\ell m}$'s, then, are the decision variables, and there would be a total of $T = I \times J \times K \times L \times M$ such variables. A <u>schedule</u> for a given interrogation period would specify the value (1 or 0) of each of the decision variables. It follows that there would be 2^T possible schedules if there were no restrictions or constraints. A practical schedule, however, must take into account several restrictions on the operation of the system. For example, a shore station would not be able to receive data from more than one platform on the same frequency and channel in the same time slot because of interference. This requirement can be expressed mathematically as

$$\sum_{m=1}^{M} X_{ijk\ell m} \leq 1 \text{ for all } i, j, k, \ell.$$

There also may be a requirement that each platform should not send its data more than once, or

$$\sum_{\ell=1}^{L} \sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{i=1}^{I} X_{ijk\ell m} \leq 1 \text{ for all } m.$$

There will be many other similar constraints on the schedule arising from equipment limitations and failures, interference, and nontechnical or administrative requirements. These can also be expressed mathematically.

A <u>feasible</u> schedule is a set of values for the decision variables that satisfy all the constraints.

Now let r_{ijm} be the probability that the message from platform m will be successfully received at station i on frequency j. For each of the $X_{ijk\ell m}$'s there will be a corresponding probability. We assume that this probability does not change from channel to channel for a given HF frequency band, nor from time slot to time slot within an interrogation interval. We can calculate these r_{ijm}'s using the HF computer prediction program developed by ITS (Barghausen et al., 1969). Let V_m be the relative value of the data from buoy m on some arbitrary scale. This variable can be chosen to reflect the fact that data from one area of the ocean may be more valuable than data from another area (e.g., because of a hurricane in one area) or that there are so many mobile platforms in one area that additional data are redundant and therefore of less value. The expected value for the message from buoy m is then $V_m r_{ijm}$, i.e., the value of the message itself multiplied by the probability that it will be received successfully, if it is assigned to station i on frequency j. This product is a measure of the relative merit of that assignment.

The next problem is to define the relative merit of one schedule versus another. One logical definition would be that schedule A is better than schedule B if the sum of the expected values of A is greater than that of B. An optimum schedule would then be defined as the feasible set of $X_{ijk\ell m}$'s that has the largest total expected value (E). The scheduling problem then is to maximize

$$E = \sum_{m=1}^{M} \sum_{\ell=1}^{L} \sum_{k=1}^{K} \sum_{j=1}^{J} \sum_{i=1}^{I} X_{ijk\ell m} \; r_{ijm} \; V_m$$

for all $1 \le i \le I$, $1 \le j \le J$, $1 \le k \le K$, $1 \le \ell \le L$, and $1 \le m \le M$ subject to constraints like those noted earlier. The problem is also subject to the restriction that the $X_{ijk\ell m}$'s be ones or zeros. This can be expressed mathematically as

$$X_{ijk\ell m} \in \{0, 1\} \text{ or } X_{ijk\ell m} = X^2_{ijk\ell m} \text{ for all } i, j, k, \ell, m.$$

Maximization problems of this type are referred to as "integer programming problems with 0-1 variables", and there are many algorithms for their exact solution.

The question remaining is whether on an operational basis it is more practical (in terms of computer time) to solve the IGOSS scheduling problem exactly by use of one of the existing algorithms (or derivation thereof) or by some heuristic method that does not guarantee an optimum solution. The answer depends on how many variables are involved in the model, the efficiency of the exact algorithm, and the accuracy and efficiency of the heuristic techniques that might be adopted or developed.

3.3 Examples of Solution Techniques

To clarify the principles stated in section 3.2, consider a simplified scheduling problem involving three platforms (A, B, and C) and three shore stations (1, 2, 3). Assume the expected values ($r_{ijm} \times V_m$) for the different possible assignments are as follows:

	1	2	3
A	50	40	100
B	20	80	60
C	30	70	90

The 50 under station 1 for platform A might correspond to a relative value (weight) of 100 multiplied by a reception probability of 50 percent. (Note that the frequency and time slot variations are not considered in this simplified example.)

Assume for constraints that a shore station can handle only one platform and that each platform sends to only one shore station. We then want to maximize

$$E = 50X_{1A} + 40X_{2A} + 100X_{3A} + 20X_{1B} + 80X_{2B} + 60X_{3B} + 30X_{1C} + 70X_{2C} + 90X_{3C}$$

subject to

$$X_{1A} + X_{2A} + X_{3A} = 1,$$
$$X_{1B} + X_{2B} + X_{3B} = 1,$$
$$X_{1C} + X_{2C} + X_{3C} = 1,$$
$$X_{1A} + X_{1B} + X_{1C} = 1,$$
$$X_{2A} + X_{2B} + X_{2C} = 1,$$
$$X_{3A} + X_{3B} + X_{3C} = 1,$$

and

$$X_{im} = 1 \text{ or } 0 \text{ for all } i, m,$$

where $X_{1A} = 1$ means platform A is assigned to shore station 1 and $X_{1A} = 0$ means platform A is not assigned to station 1, etc.

Consider now a simple assignment method. Pick the largest expected value in the table and make the corresponding assignment (in the example, set $X_{3A} = 1$). This excludes any further assignments from that row and column to meet the constraints. In the remaining portion of the table, pick the largest expected value and make that assignment ($X_{2B} = 1$). Continue this until all assignments have been made. Using this method, we have as a schedule

$$X_{3A} = X_{2B} = X_{1C} = 1$$

$$X_{1A} = X_{2A} = X_{1B} = X_{3B} = X_{2C} = X_{3C} = 0,$$

and a total expected value, E, of

$$E = 100 + 80 + 30 = 210.$$

Now consider the solution by enumeration of all possible schedules. There are $2^9 = 512$ possible schedules ranging from the X's being all zeros to all ones. Of these, only six are feasible. They are

$$X_{1A} = X_{2B} = X_{3C} = 1 \qquad E = 220^*$$

$X_{3A} = X_{2B} = X_{1C} = 1$ E = 210

$X_{3A} = X_{1B} = X_{2C} = 1$ E = 190

$X_{1A} = X_{3B} = X_{2C} = 1$ E = 180

$X_{2A} = X_{3B} = X_{1C} = 1$ E = 130

$X_{2A} = X_{1B} = X_{1C} = 1$ E = 90

Note that the schedule marked with an asterisk gives a better (higher) total value than the one from the simple rule described in the previous paragraph. This example serves to illustrate the limitations of a heuristic method. Of course, complete enumeration is not practical for solving problems with a large number of variables because of the exponential increase in the number of solutions and the addition of more complex constraints.

Having given examples of solutions to the scheduling problem using both a heuristic method and total enumeration, let us consider an exact technique that is more efficient than total enumeration. The method to be illustrated was chosen because it is easily understood, not because it is necessarily the method that would be recommended for the IGOSS problem. It is referred to as <u>implicit enumeration</u> because a large percentage of schedules that cannot be solutions are excluded from consideration and is based on a method discussed by Lawler and Bell (1966). As an illustration, consider the following scheduling problem involving three shore stations and five platforms:

	1	2	3
A	10	30	70
B	40	70	30
C	50	40	40
D	20	60	80
E	20	30	50

For constraints, assume that stations 1 and 2 can handle a maximum of two platforms each and station 3 can handle only one. Also assume that each platform will be assigned once at the most. Thus we want to maximize

$$E = 10X_{1A} + 30X_{2A} + 70X_{3A} + 40X_{1B} + 70X_{2B} + 30X_{3B} + 50X_{1C} + 40X_{2C} + 40X_{3C} + 20X_{1D} + 60X_{2D} + 80X_{3D} + 20X_{1E} + 30X_{2E} + 50X_{3E}$$

subject to the constraints

$$X_{1A} + X_{2A} + X_{3A} \leq 1,$$

$$X_{1B} + X_{2B} + X_{3B} \leq 1,$$

$$X_{1C} + X_{2C} + X_{3C} \leq 1,$$

$$X_{1D} + X_{2D} + X_{3D} \leq 1,$$

$$X_{1E} + X_{2E} + X_{3E} \leq 1,$$

$$X_{1A} + X_{1B} + X_{1C} + X_{1D} + X_{1E} \leq 2,$$

$$X_{2A} + X_{2B} + X_{2C} + X_{2D} + X_{2E} \leq 2,$$

$$X_{3A} + X_{3B} + X_{3C} + X_{3D} + X_{3E} \leq 1,$$

and

$$X_{ij} = \{0, 1\} \text{ for } i = 1, 2, 3, \text{ and } j = A, B, C, D, E.$$

A solution S then would be a set of 15 numbers each 0 or 1, that is,

$$S = (X_{1A}, X_{2A}, X_{1B}, X_{2B}, X_{3B}, X_{1C}, \ldots \ldots \ldots X_{3E}).$$

There would be 2^{15} such solutions ranging from (1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1) to(0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0). Now make the definition that S is less than or equal to S' if and only if each component of S is less than or equal to its corresponding component in S'. Thus if

$$S = (X_{1A}, X_{2A}, X_{3A}, X_{1B}, X_{2B}, X_{3B}, X_{1C} \ldots \ldots \ldots X_{3E})$$

and

$$S' = (X'_{1A}, X'_{2A}, X'_{3A}, \ldots \ldots \ldots \ldots \ldots \ldots X'_{3E}),$$

then $S \leq S'$ if and only if $X_{ij} \leq X'_{ij}$ for all i = 1, 2, 3, and j = A, B, C, D, E. This is referred to as vector partial ordering. For example, (0, 1, 0) < (0, 1, 1). Note that some solutions are not comparable, such as S = (0, 1, 1) and S' = (1, 0, 0), in which case S is not less than S' nor is S' less than S. We will make use of this partial ordering definition in our subsequent algorithm. If we interpret solutions as binary numbers and list them in descending order from all ones downward (i.e., numerically ordered), we will note an interesting thing. For any solution S, the solutions following (S-1, S-2, ...) may or may not be less than S in vector partial ordering. Consider the following solution, S, to our example, and some solutions that follow it in numerically descending order:

$$S = (0,1,0,1,0,0,1,0,0,0,1,0,0,1,1),$$

$$S-1 = (0,1,0,1,0,0,1,0,0,0,1,0,0,1,0),$$

$$S-2 = (0,1,0,1,0,0,1,0,0,0,1,0,0,0,1),$$

$$S-3 = (0,1,0,1,0,0,1,0,0,0,1,0,0,0,0),$$

and

$$S-4=S^* = (0,1,0,1,0,0,1,0,0,0,0,1,1,1,1).$$

Note that $S-1 < S$, $S-2 < S$, and $S-3 < S$ but that S^* is the first solution that is not less than S in vector partial ordering. For <u>any</u> S we can compute S^* in the following way. Interpret S as a binary number, add 1 to obtain $S + 1$, and do a logical AND between S and $S+1$, to get $S^* + 1$ and then subtract 1 to get S^*. (A logical AND is performed by comparing each component in S with the corresponding component in $S+1$. If the corresponding components are both 1 the result is 1. If one or the other is 0, or if both are 0, the result is 0.) For our example

$$S = (0,1,0,1,0,0,1,0,0,0,1,0,0,1,1),$$

$$S+1 = (0,1,0,1,0,0,1,0,0,0,1,0,1,0,0),$$

$$S \text{ AND } S+1 = S^*+1 = (0,1,0,1,0,0,1,0,0,0,1,0,0,0,0),$$

and

$$S^* = (0,1,0,1,0,0,1,0,0,0,0,1,1,1,1).$$

The use of partial ordering comes about in the following way. In the equation for E, all the coefficients of the X_{ij} binary variables are positive. If we let E(S) be the value of the objective function with solution S, then it follows with a little reflection that if $S' < S$ in vector partial ordering then $E(S') < E(S)$. That is S' cannot be a better (higher) solution than S. Going back to our previous example of S, S-1, S-2, S-3, and S*, if our best solution so far is $\hat{S}$ and if S does not increase the objective function, then neither can S-1, S-2, or S-3 and we can skip over them and go directly to S*. If S does improve the solution, by the same reasoning we can still skip to S* after saving S. In the actual algorithm, we would not need to list, evaluate the objective function, or test for feasibility the solutions lying between S and S*; instead, we could compute S* by the method given above and proceed directly. This saves considerable computation time and is much more efficient than total enumeration.

A similar technique can be used in testing whether the solution violates any of the constraints. Returning once more to our example of S, S-1, S-2, S-3, and S*, if S* + 1 (in this case S-3) exceeds a constraint, all solutions between S and S* + 1 clearly also exceed the constraint and again we can skip. A simplified block diagram of the algorithm based on these techniques is shown in figure 2. The current solution being considered is S, $\hat{S}$ is the best solution obtained thus far, E (S) and E $(\hat{S})$ are the values of the objective function for these two solutions respectively, and S* is the first solution following S that is not less than S in vector partial ordering.

In block number 1, S is set to all ones and E $(\hat{S})$ is set to minus infinity. In block 2, S* + 1 and S* are computed by means of the logical AND operation described above. Next, in block 3, E (S) is computed and compared with E $(\hat{S})$. If S is <u>not</u> a better (higher) solution, then we

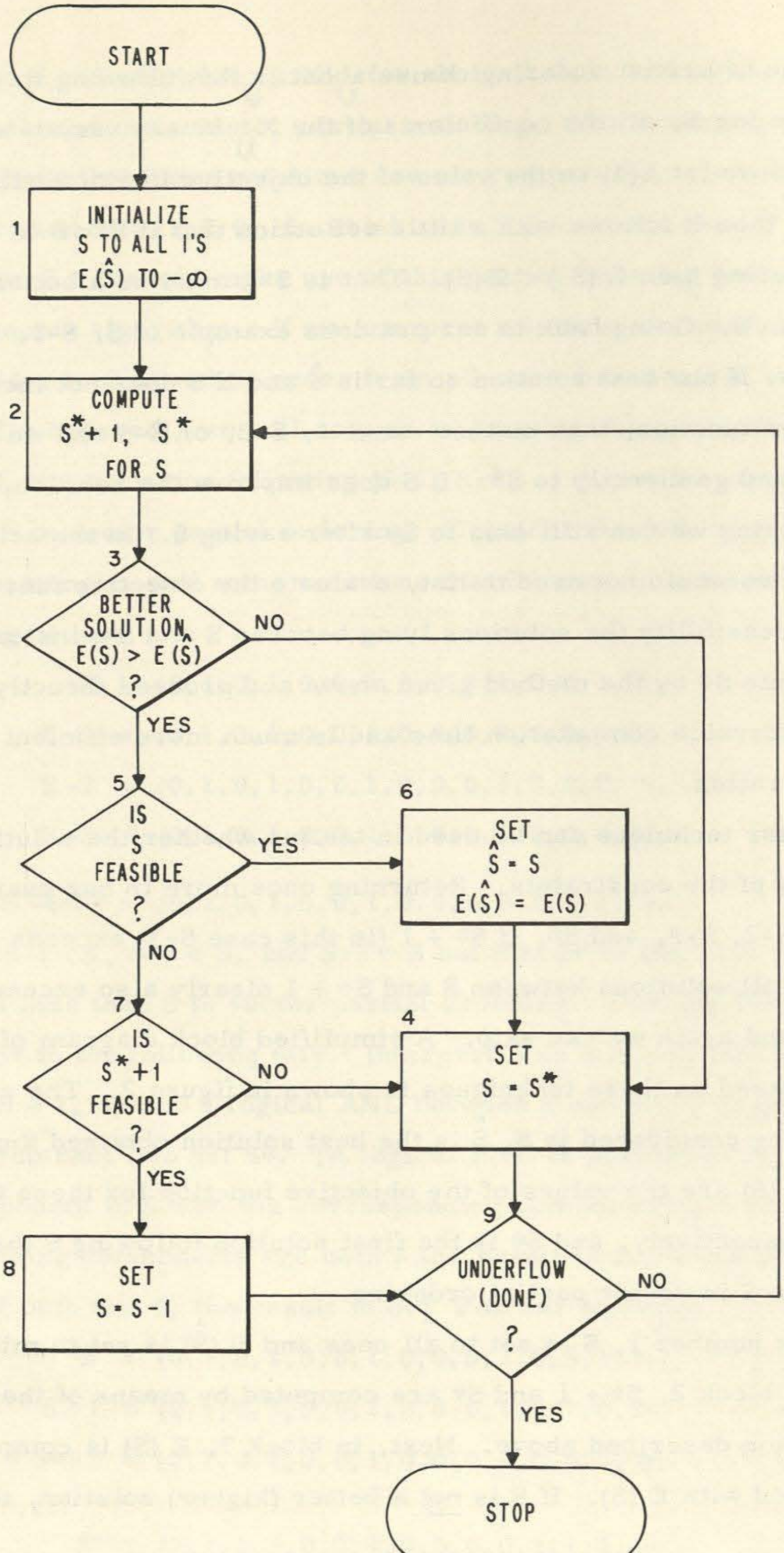

Figure 2. Block diagram of implicit enumeration algorithm.

can set our next solution (S) to S* (block 4) and repeat block 2. If S is a better solution, it must be tested for feasibility (block 5). If the solution does satisfy all the constraints, then the new best solution is S and the new value of the objective function is E (S). Thus in block 6, $\hat{S}$ is set equal to S and E ($\hat{S}$) is set equal to E (S). Since the next possible solution is S*, S is set equal to S* and the process is continued through block 2. Returning to block 5, if S is infeasible, we test S* + 1 for feasibility (block 7). If it is infeasible, then all solutions between S and S* must also be infeasible and we can again skip to S*. If S* + 1 is feasible, no skipping is possible and the next solution in numerical order (S-1) is computed (block 8) and considered. Each new solution is tested (block 9) to see if all zeros have been equalled or passed; if so, we are done and the optimum schedule is $\hat{S}$.

Table 1 is a set of solutions taken from the middle of the solution to our sample problem. Note that over half of the solutions are skipped, a significant savings.

4. CLOCK-CONTROLLED VERSUS SHORE-INITIATED DATA TRANSMISSION

The data collected by the platforms must be transmitted to shore at regular intervals for processing and dissemination. The IGOSS concept calls for transmissions at the synoptic hours of 600, 1200, 1800, and 2400 GMT. These transmissions can be initiated by a clock on the platform or by a transmission from a shore station. The relative merits of these two alternatives are summarized in table 2, where each alternative is divided into two parts according to whether "housekeeping" and reprogramming of the platform is possible from the shore. Housekeeping means remotely testing and maintaining the buoy during nonsynoptic

Table 1. Sample Solutions and Logic for the Implicit Enumeration Technique.

Solution(s)	Value of Objective Function (E (S))	Comment
		Best solution so far assumed to be 220
010010100001100	250	Improvement feas., skip to S*=010010100001011
010010100001011	280	Improvement infeas., S*+1 feas., no skip possible
010010100001010	230	No improvement, skip to S*=010010100001001
010010100001001	250	No improvement, skip to S*=010010100000111
010010100001000		
010010100000111	250	No improvement, skip to S*=010010011111111
010010100000110		
010010100000101		
010010100000100		
010010100000011		
010010100000010		
010010100000001		
010010100000000		
010010011111111	440	Improvement, infeas., S*+1 feas., no skip possible
010010011111110	390	Improvement, infeas., S*+1 infeas., skip to S*=010001111111101
010010011111101	410	Improvement, infeas., S*+1 infeas., skip to S*=010001111110011
010010011111100		
010010011111011	420	Improvement, infeas., S*+1 infeas., skip to S*=010001111110111
010010011111010		
010010011111001		
010010011111000		
010010011110111	360	Improvement, infeas., S*+1 infeas., skip to S*=010001111101111
010010011110110		
010010011110101		
010010011110100		
010010011110011		
010010011110010		
010010011110001		
010010011110000		
010010011101111	380	Improvement, infeas., S*+1 infeas., skip to S*=010010011011111 (There are 16 solutions between this one and S*.)

periods. This might include, for example, calibration checks and monitoring fuel and/or battery charge levels. Reprogramming might include, for example, changing receiving or transmitting frequencies or channels, times of measurement, and data rates. The need for housekeeping and the part of reprogramming connected with data collection depend on factors beyond the scope of this study. If housekeeping is called for on the basis of these other factors, it will have a strong effect on the conclusions reached in this section. Housekeeping requires that (1) the buoy be equipped with a receiver, decoding, duplexer, and command equipment and (2) that the shore stations be equipped with transmitting equipment. With this equipment available, readout by interrogation could be accomplished at very little added cost.

The items listed in table 2 are important in arriving at a decision. Item 1 is the housekeeping function just discussed. Item 2 concerns the reliability of the shore-to-platform interrogation link. Successful readout by interrogation requires that

(a) the transmission from the shore station to the platform must produce a sufficient signal-to-noise ratio, so that

(b) the interrogation message can be successfully decoded to initiate the data transmission to the shore, and

(c) the received signal at the shore station must be sufficient to produce an acceptable error rate.

Table 2. Comparison of The Merits of

1. Remote servicing of buoy for recalibration and other purposes possible?
2. Lost data because of poor communication link from shore to buoys possible?
3. Retransmission request possible?
4. Unscheduled readouts possible?
5. Shore-controlled channel change possible for ships/drifting buoy and congested areas?
6. Shore-controlled time slot change possible for ships/drifting buoys and congested areas?
7. Shore-controlled frequency changes possible?
8. Shore station synchronization of transmissions required?
9. Clock resetting possible?
10. Shutdown of defective transmitter possible?
11. Possibility of unwanted (interfering) transmission because of noise/interference?

Interrogation and Clock Controlled Readout.

With Housekeeping and Reprogramming Capability		No Housekeeping and Reprogramming Capability	
Interrogation	Clock	Interrogation	Clock
Yes	Yes	No	No
Yes	No	Yes	No
Yes	No	Yes	No
Yes	No	Yes	No
Yes	Yes	No	No
Yes	Yes	No	No
Yes	Yes	No	No
Yes	No	Yes	No
Yes	Yes	No	No
Yes	Yes	Yes*	No
Yes	No	Yes	No

*By not interrogating until serviced.

Clock-initiated readout on the other hand requires only (c). If clock reliability is not a factor, initiation by interrogation is inherently less reliable. On the other hand, the probabilities associated with (a), (b), and (c) above are not independent. The higher transmitter power available at the shore, the isolation from man-made radio noise at the platform, and the use of coding that permits (b) even under poor conditions means that the shore-to-platform link should be much more reliable than the platform-to-shore link. Because of path reciprocity, if the shore-to-platform path would make successful data transmission possible, it is extremely likely that the interrogation would be successful. Thus the reduction in reliability may not be significant.

The interrogation alternative also permits retransmission either later in the synoptic interval or during nonsynoptic hours at the option of the shore station (see item 3 in table 2). After the IGOSS system is fully implemented, it may be undesirable to permit reinterrogation during the synoptic period as has been indicated by the Joint WMO/IOC Group of Experts on Telecommunications (1969). In the interim period, however, retransmission could be considered in cases of unsuccessful data transmission.

Closely related to item 3 is item 4, which deals with the possibility of readouts during nonsynoptic periods. This would be especially valuable during severe weather/ocean conditions. Using the interrogation system would permit, when desired and with little additional complexity, more frequent or more detailed readouts during such periods of special interest. On the other hand, in the clock-controlled system an alarm system could be used whereby transmissions would be made when weather/ocean conditions exceeded some threshold.

Items 5, 6, and 7 in table 2 relate to the changing of the buoy transmission frequency, channel, and time slot. The diurnal variation in propagation conditions may require use of different frequencies during some of the synoptic hours in order that reliable transmissions be maintained. These frequency changes could be accomplished either by a fixed program on the platform or by reprogramming from the shore. The latter is desirable to cover seasonal variations and is almost a necessity in the case of drifting or mobile platforms to allow for their changing location. For the final system configuration, a reprogrammable frequency capability is therefore highly desirable. Channel and time slot changes can be used to avoid interference and conflicts in assignments. This flexibility will be particularly useful as system use approaches capacity. The increase in performance when reprogramming is possible can be estimated by running the IGOSS data transmission system simulation program currently under development at ITS (Hatfield and Adams, 1969).

As concluded earlier, the decision regarding remote reprogramming has a strong bearing on whether interrogation or clock-controlled readout is used. Interrogation requires that the platform be able to receive all usable frequencies at all times or that the receiver can be programmed. However, reprogramming capability with clock-controlled data readout also requires changes in platform receiver frequency for reliable reception of the commands. This requirement is not as important, however, because the time of transmission could be tailored to the available frequency rather than having the frequency tailored to the time of transmission, as during synoptic periods.

Because of the relatively high transmitter power available at the shore, the group of experts has recommended that the shore station transmissions be limited to specific intervals during the synoptic period. This means that the shore stations must be synchronized on a worldwide basis; a requirement does not exist for clock-controlled transmissions, as reflected in item 8, table 2. However, a clock-controlled system does place stringent requirements on the clock on the platform since (1) it must remain accurate during the entire period between platform servicing, and (2) it must be highly reliable because erratic transmission times not only would cause loss of the data from the platform itself but could also interfere with data transmissions of other platforms. A reprogramming capability could allow for resetting the clock (item 9) but may not be able to prevent erratic transmissions.

Relatively minor factors (items 10 and 11) are that it would be easier to shut down a defective transmitter in a reprogrammable system than in a nonprogrammable one and that there is a small but finite probability of noise or interference triggering an unwanted transmission in the interrogation system. With a nonprogrammable interrogation system, problems due to a defective platform transmitter may be overcome in some cases by simply not sending the interrogation signal.

The final factor, not included in table 2, is relative complexity. This should include both the complexity of the equipment required and of management or coordination problems. In strictly qualitative terms, a clock-controlled system without housekeeping and reprogramming is by far the least complex in both equipment and management, while an interrogation-controlled system with full housekeeping and reprogramming features is the most complex. The difference in complexity between a clock-controlled readout system that is reprogrammable and an interrogation-controlled system is not great in terms of equipment, but the latter system does require shore station coordination.

On the basis of this discussion and recognizing that the ability of providing reprogramming and housekeeping functions is in any event desirable, we recommend that an interrogation-controlled system be accepted for IGOSS. The benefits of obtaining readouts at nonprogrammed times and the possibility of requesting retransmission of data appear to outweigh the disadvantages of slightly lower reliability and shore station synchronization. We also recommend that the operational advantages of reprogramming, be further investigated by means of the simulation program.

The buoys may, of course, range widely in size and complexity and clock-controlled types may be the most appropriate for the lower capability ones.

5. HIGH-SPEED SEQUENTIAL VERSUS LOW-SPEED PARALLEL DATA TRANSMISSIONS

Each of the six frequency bands set aside by the ITU for ocean data transmission are 3.5 kHz wide. The amount of information (data) that can be transmitted in a given interval of time (the data rate) is limited by this bandwidth and the characteristics of the HF channel. This bandwidth can be used in many ways. At one extreme, a number of buoys could each use a small slice of it (say 200 Hz) simultaneously and each send data to the shore station using slow speed transmission. At the other extreme, each buoy in sequence could use the total bandwidth to send data at a high speed, providing sequential, high speed transmission. The feasibility and relative advantages of these two approaches are discussed below.

The maximum data rate that can be obtained on a given channel is affected not only by the bandwidth and signal-to-noise ratio but also by the distortion of the signal by the channel itself. This distortion is highly variable and can be quite severe on an HF channel. The principal type of distortion is produced by the signal arriving at the receiver via more than one path, resulting in multipath. For example, the signal may arrive at the receiving antenna via a path on which there is only one reflection from the ionosphere, but also via a path with two reflections from the ionosphere and an intervening reflection from the ground. Since the "two-hop" signal travels a longer distance than the "one-hop," it will arrive later. If a sharp pulse, say 1 ms, is transmitted, the received pulse can be spread in time by as much as 2-4 ms. If high data rates are achieved by shortening the transmitted elements in time, with correspondingly high bandwidths, the received elements may partially or wholly overlap and thus produce a high error rate. For this reason the element length cannot be indiscriminately shortened. In practice, lengths of approximately 10 ms are commonly used in HF modems. This, in turn, reduces the bandwidths requirements to about 100-200 Hz and results in a maximum keying rate of about 100 bits/sec. To increase the data rate when a bandwidth of several kHz is available, frequency division multiplex (FDM) is often used. In FDM, the available bandwidth is divided into a number of independent channels. A typical example is where a 3-kHz band is divided into 16 channels, each operating at 100 bits/sec. Thus a total of 16 x 100 = 1,600 bits/sec could be achieved. Methods exist by which the entire bandwidth is used without channelizing, but they are usually quite complex, not extensively proven in practice, and not internationally accepted. For a more complete analysis of modem types for IGOSS, the reader is referred to a report by Akima (1969).

It is important to note the distinction between the case where FDM is used for a single platform (for sequential high-speed transmission) and the case where each platform is assigned a different channel in the band available (parallel low-speed alternative). The sequential, high speed alternative has certain advantages that make it worthy of consideration. Among these are:

(a) Less severe requirements on shore station receiver dynamic range and channel selectivity. In parallel slow-speed transmission, the channel signals would arrive from several platforms at the same time and could be of widely different strengths. With the sequential high-speed technique, on the other hand, the signals at any given time would originate from a single platform. This would ease the receiver design requirements and/or put less constraints on which platforms are assigned in the same frequency band and time slot.

(b) Possibility of using directive receiving antennas with higher gain at the shore stations, although this would require either a steerable antenna or a greater number of antennas to provide the desired coverage in azimuth. The necessity for reception from several platforms at the same time implies that an antenna with a wider beamwidth be used, which, of course, would lead to less gain than otherwise possible.

(c) No channel changes. Since the full bandwidth is used, channel changing for ships or drifting buoys would not be required.

The disadvantages of a sequential, high speed system are considerable, however, and virtually eliminate this technique from serious consideration. The major ones are:

(a) An unchannelized, broad-band modulation system, which would be the most attractive choice for sequential operation has not been proven.

(b) In an FDM system the transmitter power is divided among all the channels. To obtain the same error rate performance the transmitter power capability must be raised accordingly. (Power consumption per transmission, however, does not increase.)

(c) Use of FDM techniques require a linear RF amplifier to prevent intermodulation distortion. The final amplifier must therefore be operated as a class AB or B amplifier, with significantly lower efficiency than a class C amplifier, which can be used with a single channel system (as in parallel, low-speed transmission). Also, linear amplifiers are less tolerant to changes in operating conditions and place more stringent requirements on the power supply system. Equipment on the platform would also be considerably more complex and costly than for a single channel system, and the high ratio of peak-to-average power in an FDM system requires a larger final amplifier than that used for a single channel operation.

(d) The short message duration in a sequential high-speed system may result in several design difficulties. For example,

(1) it may not be possible to shorten the synchronization acquisition time in the same ratio as the message time (compared to the parallel low speed system), with the result that the available time would be less efficiently used;

(2) a higher degree of accuracy in system coordination would be required to maintain the same message time-to-guard time ratio (and thus time use factor); and

(3) it may be considerably more difficult to find an effective error correcting coding technique. (In general, errors in HF digital transmission occur in bursts, and error correcting codes for HF channels usually incorporate some form of time spreading to overcome this effect.)

In view of the above, we conclude that the parallel slow-speed alternative is the most feasible technique for the data transmissions.

The type of modulation in the channels (FSK or PSK) will not be discussed here since it has been covered in detail by Akima (1969).

6. CONCLUSIONS AND RECOMMENDATIONS

It is recommended that work be continued on the development of the computer model of the ocean data transmission system and that exact and heuristic algorithms for the optimization of station-frequency-channel-time slot assignments be investigated.

Data transmissions from platforms should be initiated by an interrogation signal, especially if the platforms must be equipped with a receiver and command equipment for other reasons. The effect on system performance of channel and frequency changes from shore should be evaluated, based on the computer model.

It is also recommended that transmissions from several platforms be made simultaneously at relatively slow speed, with use of separate channels in the frequency bands available. Work regarding the type of modulation in the channel and the maximum permissible number of channels per frequency band or the maximum differences in signal levels in the same frequency band is being carried out in a separate study.

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GPO 857-464