MODEL FOR INTERACTIVE DESIGN AND ANALYSIS OF COMMUNICATION SYSTEMS

Mr. Richard W. Moss, Senior Research Engineer
Georgia Tech Engineering Experiment Station

Dr. Robert W. Rice, Research Engineer
Georgia Tech Engineering Experiment Station

Mr. Peter K. Leong, Project Engineer
Rome Air Development Center, DICEF

I ABSTRACT

The basic concepts developed for the implementation of an interactive communication simulation program are described. The problems considered include the means of generating mathematical models, the accuracy of those models, the means of exercising the configured models, and the speed of the exercising process.

II INTRODUCTION

The purpose of this paper is to describe an interactive communication simulation model undertaken for the Digital Communications Experimental Facility (DICEF) at Rome Air Development Center (RADC) by the Communications Technology Group of the Engineering Experiment Station at Georgia Tech. The objective of this effort was to develop the concept and structure for implementation of a large scale simulation program for studying digital communication systems. The concepts developed have been illustrated by the implementation of a demonstration program employing the formulated concepts.

III APPROACH

The method of approach in this effort was to formulate concepts for an interactive communications system model that will provide answers in a meaningful manner for a wide range of digital communication system configurations. The general approach has been (1) to identify input-output characteristics of the design and modeling problem including indices of performance, (2) based on the input-output structure required, to determine the levels of modeling needed, (3) to formulate modeling concepts at the system and function level, (4) to match up the programming structure with the modeling concepts, and (5) to structure the modeling concept for interactive operation.

For convenience in discussions and for brevity the interactive analysis formulated as a part of this effort will be referred to as MIDACS for Model for Interactive Design and Analysis of Communication Systems.

The first step in developing a simulation model such as MIDACS is the identification of important modeling characteristics required. Consideration of the anticipated use of MIDACS has resulted in the identification of five important characteristics:

- Applicability
- Speed
- Accuracy
- Ease of use and
- Expandability

The simulation model should be applicable to a broad range of problems. This means that it should have the ability to represent the operation of a large variety of communication systems. Typically, there is necessity for diversity in structure to accommodate modulation form, type of channel, or type of receiving circuitry. However, structural flexibility should not be viewed as being sufficient to insure broad applicability. It is also necessary to have the ability to specify or evaluate a wide range of system parameters including such things as data rate, signal attenuation, noise level, probability of detection error, signal-to-noise ratio, channel bandwidth, etc.

The interest in communications simulation is based on the premise that a computer-oriented analysis will proceed more quickly and accurately than a similar analysis carried out manually. The validity of such an assumption is in part dependent upon the speed with which one can set up a problem using the computer simulation. For the communications analyst, problem setup will consist of structuring a block diagram of the system of interest and assigning numerical values to the characterizing parameters.

An important part of the MIDACS concept is that the problem setup will be carried out both interactively and graphically. If the programming for the interactive graphics is efficient, the user will be able to proceed quickly to the evaluation/calculation phase of the simulation. It is the calculation phase that will tend to have the greatest impact on the perceived speed of analysis for two reasons. First, in many complex simulations the number of computations to be performed will be immense and will therefore require an appreciable amount of time. Second, it is anticipated that during the computation phase the user/analyst will not be actively involved in the simulation, and this effect alone will tend to accelerate his sense of elapsed time.

The matter of simulation accuracy is difficult to assess, but three major components of accuracy may be identified. The first and most fundamental aspect of simulation accuracy is tied to the relationship between the system being simulated and the model chosen to represent that system. It is important to realize that only the analyst knows the relationship between the simulation structure and the physical system that the structure represents. The assessment of accuracy for this aspect of simulation must be made by the user.

The next aspect of accuracy concerns the relationship between an ideal model element and the mathematical representation of that element. Typically, the mathematical representation will be an approximation of the actual element, for example, a series solution or a piece-wise linear representation. Truncation errors or the degree of approximation will obviously have a direct effect on accuracy. It is possible to exercise a high degree of control over the accuracy of representation of a single element, but it should be realized that in any realistic system model there will be many elements, and the accuracy of each of the elements will contribute to the error. In general, this overall accuracy is difficult to evaluate.

The third aspect of accuracy is related to the techniques employed in software development for the simulation model. When calculations are carried out manually, the analyst rarely has to worry about the order in which the basic operations such as multiplication and addition are performed since the commutative and distributive principles apply. For the computer these principles are not always applicable and can thus influence the accuracy of calculated results. Two of the more serious contributors to this problem are truncation and round-off errors which result from the finite word length of all computers.

Experience has shown that simulation models which require a highly-detailed knowledge of either computers or a simulation language find little use. Since it is desired that MIDACS gain wide acceptance by communication analysts, it is imperative that the model be easy to use. Ideally, the inexperienced analyst should be able to exercise the model with little or no external assistance, and at the same time the experienced user should not be subjected to lengthy or detailed descriptions of basic operations. Thus, the program should be highly interactive, but it should be flexible in the amount of descriptive detail provided to the user.

Since any simulation model can contain only a finite library of simulation elements, and since it is impossible to anticipate every structural element desired by future program users, it is desirable to structure the program so that it can be expanded easily by the addition of new or alternate simulation elements. This approach allows the user to create representations which may be peculiar to his own interests, and it also allows the rapid addition of new communications components to the simulation element library.

IV IMPLEMENTATION

Five important modeling characteristics have been identified and discussed. It is now necessary to indicate how each of those characteristics may be incorporated into the modeling structure.

In the development of simulation concepts it has been assumed that a system model will be structured by the analyst from a set of models of basic digital communication functions. For a modeling structure of this type three things must be done to insure that the overall simulation technique is broadly applicable. First, the library of models of basic communication functions must be extensive. This means that not only should there be a wide variety of different functions in the library, but there should also be a variety of implementations of the same function. Second, each function model should contain sufficient detail to allow specification by the analyst of the important parameters affecting functional performance. For example, a user on identifying the need for a low-pass filter model should be able to specify filter type, order, ripple, bandwidth, etc. Third, the program should be capable of evaluating the performance parameters of greatest importance and widest use. It should be emphasized, however, that this does not preclude the introduction of new performance measures which either facilitate the evaluation process or enhance the understanding of system operation.

Two contributors to the time required to perform a simulation have been identified: the time required to structure the simulation model and the time required to exercise the model to obtain the desired data. Consider first the problem of model structuring. Many of the existing or planned digital communication systems conform structurally to one of a limited number of well-documented system models, and therefore the design or analysis of such systems requires only the exercise of one such common model with parametric variations. In such instances time may be saved by providing the user with a complete system model. The system model would describe a fixed system structure and would allow parametric specification in the manner employed for function models.

It is easy to envision at least one other situation in which a system model would be desirable. Consider the case where an analyst is examining new system structures. In the process of doing so he may wish to reexamine the performance of a particular system several times. This process would be very lengthy if each system exercise required a complete restructuring of the system model from function models; however, it would proceed quite rapidly if the initial system structure could be retained and identified as a system model in the simulation program's library.

The second factor contributing to the speed of the analysis is computation time. The incorporation of closed form equations for individual performance measures would provide the analyst with the means of obtaining performance data on a wide array of the more commonly used digital communications systems. For those instances where an actual simulation is to be performed, computation time may be minimized by providing a multilevel representation of the functional blocks. The levels of representation would correspond to the amount of detail included in the functional model, and it is assumed that the evaluation of a complex and/or detailed representation would require greater computation time than would the evaluation of a simpler representation.

The concept of a multilevel representation for the functional elements leads to a degree of control between computation time and accuracy. The lower bound of error, which may be defined as the square of the difference between the calculated value $\hat{x}$ and the true value x may be chosen to decrease as the level of representation is increased. In this manner the first level representation is less accurate but produces a quick answer, while a higher level is more accurate but requires greater computer processing time. The MIDACS concept includes three levels of representation.

The first step in the modeling process is the identification of the physical system to be modeled. For MIDACS, the scope of interest is actually a class of systems: digital communication systems. Next, a block diagram should be produced for each specific system of interest, and the functional blocks which are a part of that diagram should be identified. The next step requires the analyst to specify the type of model desired: system or function. Assume for the moment that a system level model is desired.

The system level model for MIDACS is a mathematical representation intended to describe one performance measure in the environment of one particular communication system, and it may be obtained either by original derivation or by reference to the technical literature. The latter alternative is somewhat more efficient since previous results can be utilized. In particular, many models are readily available from the following sources: [1], [2], [3], [4], [5], and [6].

In contrast to a system-level model, a significantly different approach is required for function-level models. The primary difference is that the function-level models are designed to accept simulated inputs and produce the corresponding outputs. It bears emphasizing that true input-output relationships are involved and not just performance measures based upon those inputs or outputs.

It has been noted that the mathematical models for functional blocks actually describe an input-output relationship. For MIDACS, a somewhat traditional approach has been taken, and inputs are generally assumed to be time domain "signals", and outputs are those time domain responses to the specified inputs.

The selection of time domain modeling bears some discussion. It is recognized that it is possible to carry out much of the modeling and simulation effort in the frequency domain, particularly for linear functions, and furthermore, it is acknowledged that there are several points in the typical communication system where frequency domain information may be of greater interest. However, there are several critical points in the typical digital communication system where time domain information is essential for assessment of system performance. One such point is the output of the data source. Rarely is this point characterized by its spectrum. A similar situation exists in the receiver's detection/decision circuitry where the need for time-domain information at this point is emphasized by timing circuitry associated with the decision circuits. Also, nonlinear functional elements, as a class, are most easily modeled in the time domain. Based upon the foregoing arguments, it has been concluded that the most efficient modeling approach lies in the time domain. This should not be viewed as a disregard of the need for spectral information, since a fast Fourier transform (FFT) algorithm is envisioned as a part of MIDACS. Thus, when spectral information is needed, the analyst may transform the time-domain data to the frequency domain.

Consider now the actual implementation of mathematical models for functional blocks. The area of system analysis has given rise to a variety of forms for describing the operation of physical systems, and four techniques will be described.

It is possible to represent a variety of communication functions by algebraic equations, and both linear and nonlinear functions are ameanable to this form of representation. The major shortcomming of the algebraic representation is that it does not account for element memory, but in recognition of the multilevel modeling concept is should be emphasized that a non-memory representation may be sufficient as an approximation in some cases.

A second approach is to represent a function by an ordinary differential equation, and then to seek a solution to that equation. Solutions have been found for many of the more commonly-encountered forms; however, the analytical solutions for these equations often have limited appeal for computer applications. This is because the steady state solution to many differential equations involves an integral for which a closed form solution is not guaranteed.

Another approach uses standard techniques for numerically solving differential equations. This approach has been elegantly developed as state variable analysis, and thus requires no further elaboration here.

The final mathematical modeling approach to be discussed was developed expressly for the simulation of continuous time systems by a digital computer. The technique, results in a difference equation in the input and output variables. This equation is obtained by using Z-transform manipulations on the Laplace transform representation of the functional element and an associated data reconstructor [7].

Of these techniques, the difference equation approach and the differential equation solving scheme are viewed as the most practical for time-domain simulation, and they were the techniques employed in the demonstration program.

During the process of function/component identification, it became apparent that certain types of functions may require special attention in the modeling process. Three such groups have been identified:

- Components generating and/or processing RF/carrier signals,
- Devices performing an encoding/decoding function,
- Devices generating random quantities.

It has been recognized that in most communication systems little if any information is contained in the carrier itself, and thus the time spent on accurately simulating the carrier component is largely wasted. This leads to the desirability of baseband modeling of both the modulation waveform and the system's RF components such as bandpass filters [8].

The advantage of software development in a high level language such as FORTRAN was apparent early in the modeling effort; however, it has been observed that simulation of encoding/decoding devices which are commonly used in digital communication systems would proceed very slowly if the model were implemented in a high level language. By comparison, such a simulation would proceed rapidly in machine or assembly level language due to the efficiency of implementing logical operations.

Random number generation for bit pattern generation or noise simulation is also commonly done in communications simulation. An ample body of literature exists which indicates that several of the more common distributions may be generated very efficiently by simple shift register operations on binary data at the machine or assembly level. It is important to realize that numbers generated by such techniques often meet certain criteria for the prescribed distribution, but these criteria are not sufficient to guarantee that all aspects of the random sequence generated will conform to the desired behavior.

Another important facet of digital communications simulation for analysis and design is the variety of performance measures which should be provided. Obvious measures include the signal-to-noise ratio and the probability of bit error. To gain insight into system performance requires other intermediate measures such as time waveforms, decision variable density functions, and spectral characteristics. All of these measures have been considered in the modeling concept, particularly in the context of accuracy and computer run-time. Simulation methods considered range from completely analytical to standard Monte Carlo approaches.

In the development of any interactive simulation program it is necessary to consider how the potential user will interact with the model. One of the guiding principles in this effort has been that a high degree of user-computer interaction is desirable. Two approaches have been used to achieve this. First, a simulation language has been developed which will allow the experienced user to structure and evaluate a system. Second, the structure for a user-computer dialogue has been established which will guide the inexperienced user step-by-step through a simulation. In both cases extensive use of graphics for input and output is employed. This includes displaying system block diagrams, graphically displaying calculated data, and the entering of information by means of a light pen.

V MIDACS APPLICATIONS

A communications systems simulation model as versatile and powerful as MIDACS is expected to be a very effective and essential in supporting the research, development, test and evaluation (RDT&E) requirements in communications-electronics systems of Air Force and other DOD organizations. We can no longer afford the luxury of a "fly-fix-fly" type acquisition practices. With MIDACS, a major portion of test and evaluation can be performed without the need of hardware thus providing a more cost effective system for operation. Some specific programs in which MIDACS will be useful for providing technical support are as follows:

a. Digital European Backbone (DEB I, II, III, and IV): For this program a "Mini-DEB" channel will be simulated to help determine equipment performance, link performance, synchronization recovery techniques, system susceptibility to natural and man-made interference, and link availability.
b. Tactical Interfaces and Mobile Message Station: An HF link will be simulated to help examine the relay capabilities in a mobile message station.
c. Jam Resistent Data Link: A line-of-sight microwave data link will be simulated to determine the merits of various antenna and modem processing techniques, separately or combined in various simulated jamming environments.
d. Imagery Transmission System: For this program various data conservation techniques can be programmed and evaluated over a variety of simulated propagation media.
e. Fault isolation in FM data communication systems - Portions of an FM data communications system can be simulated to develop

and test fault isolation and performance monitoring techniques, and specifically to develop techniques for isolating faults in the RF-IF portion of the system based on measurements at the baseband level.

ACKNOWLEDGEMENTS

The work summarized in this paper was performed under Contract F30602-75-C-0247 with Rome Air Development Center. The contributions of Dr. J. L. Hammond of the Electrical Engineering Department of Georgia Tech are acknowledged.

BIBLIOGRAPHY

[1] H. Taub, D. L. Schilling, Principles of Communication Systems, McGraw-Hill Book Company, New York, 1971.

[2] J. B. Thomas, An Introduction to Statistical Communication Theory, John Wiley & Sons, Inc., New York, 1969.

[3] P. Beckmann, Probability in Communication Engineering, Harcovrt, Brace & World, Inc., Atlanta, 1967.

[4] B. P. Lathi, Communications Systems, John Wiley & Sons, Inc., New York, 1968.

[5] S. Stein, J. J. Jones, Modern Communication Principles, McGraw-Hill Book Company, New York 1967.

[7] H. L. Van Trees, Detection, Estimation, and Modulation Theory, John Wiley and Sons, Inc., New York 1968.

[7] J. S. Rosko, Digital Simulation of Physical Systems, Addison-Wesley Publishing Company, Reading, Mass., 1972.

[8] R. A. Manske, "Computer Simulation of Narrowband Systems", IEEE Trans. on Computers, Vol. C-17, No. 4, April 1968, pp. 301-308.