G. R. PREZIOTTI, I. J. SHEPPERD, and M. D. SULLIVAN

A COMMUNICATIONS SYSTEMS TEST AND EVALUATION PROGRAM

Since 1972, APL has tested and evaluated the communications links used to deliver orders to Naval strategic forces. This program continually tests those links during normal operations and provides a quantitative assessment of the probability that the system will perform as required. Such information allows the Navy to make decisions regarding the deployment of ships, the operation of current communications systems, and the development of future communications systems. The test concept is highly automated, requires minimal operator involvement, and may be adapted to tactical or commercial systems.

INTRODUCTION

The communications links necessary to provide for the flow of commands and information are a major facet of the command, control, and communications process. Of particular importance are the communications links designed to provide a continuous capability for the delivery of orders from the highest levels of government to the individual elements of the strategic forces concerning the release or use of strategic weapons. Whether these links perform as required is a major concern; information that can confirm their performance is highly valued. In the early 1970's, the Laboratory was requested to develop a means of continually evaluating the performance of the communications systems that support the Naval strategic forces. The test and evaluation program developed in response to that request is the subject of this article. It has application not only to strategic but also to tactical and commercial communications systems.

SYSTEM CONCEPT

Navy communications systems evaluated by the Laboratory have covered the spectrum from extremely low frequencies to ultrahigh frequencies and have involved transmissions from fixed shore sites, ships at sea, aircraft, and satellite systems. Varied as these systems have been, the Laboratory's objective has remained the same, i.e., to determine the probability that a given communications system will provide the service for which it is designed. This is done by testing the communications links in their normal operational environment[1] during regularly scheduled day-to-day operations. As data are collected in an operational environment, the testing must have minimal impact on the normal operations of the system. Consequently, special data collection and recording systems developed by APL are used to gather the necessary communications data. The current unit, the Modular Data Collection and Recording System, is discussed elsewhere in this issue.

INITIAL TEST AND EVALUATION PROGRAM

The initial communication test and evaluation program was developed to evaluate the high frequency component of a submarine radio Teletype broadcast (50-baud frequency shift keying using 7-bit Baudot characters) used to deliver messages to nuclear-powered Fleet Ballistic Missile submarines (SSBN's). The objective was to determine the probability that a standard message order could be delivered to the SSBN's by this broadcast. These message orders consist of a set number (called N) of characters that are transmitted using the phonetic-letters-spelled-out technique. That is, a word is transmitted in place of each character in the message text (e.g., Bravo is substituted for the character b). Each message is repeated three times on the broadcast so that the receiving communications personnel may combine ungarbled portions of each copy to obtain a single correct copy.

Normally, test transmissions of actual operational message orders can only be made infrequently so that operations of the command and control structure and patrol operations of the SSBN's are not affected. As a consequence, a data base for the evaluation of communications performance relying on such transmissions would be sparse. In order to expand the data base, the Laboratory proposed and implemented a system to supplement the test transmissions of actual message orders with frequently transmitted technical test messages (described below). These automatically transmitted, received, and processed test messages require minimal time and attention by the transmission facilities and the crews of the SSBN's. This vastly expands the data base as the test messages can be transmitted two or three times per hour.

The technical test message is comprised of a series of 13-bit Barker sequences (a specific pseudorandom sequence of 0's and 1's chosen for its desirable cross-correlation properties) repeated to obtain the required message length. This technical test message
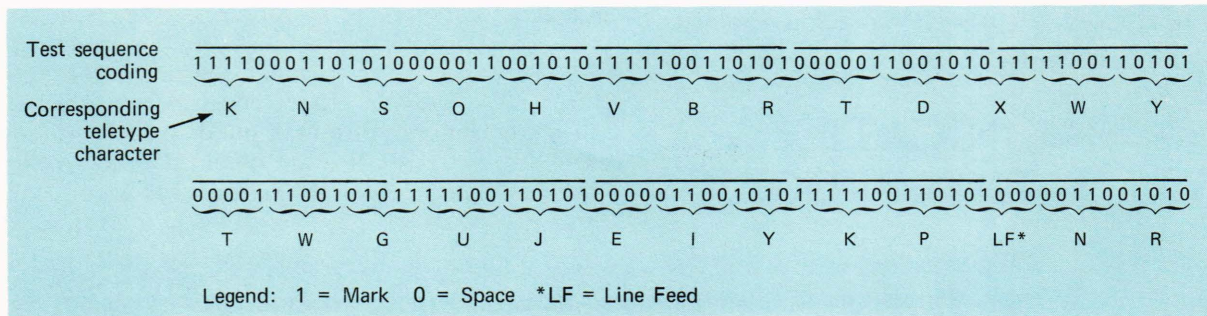
Figure 1 — This technical test message, comprised of a repeated set of ten 13-bit Barker sequences, is used to collect communications parameters by automatically activating test equipment.

(shown in Fig. 1) was selected because it can maximize the probability of recognizing the code sequence in the presence of errors and minimize the probability of falsely recognizing some other sequence. The repetitive sequence also allows a reasonable measurement of channel error rate without the need to store excessive information in the test instrumentation processor.

The APL-developed Modular Data Collection and Recording System, which automatically recognizes the test message, is placed at the transmission sites and at the receiving SSBN's, and records the test data on magnetic tapes for processing and analysis at APL. The equipment is used at the transmission sites to record the time the test messages were transmitted and to monitor the quality of the transmission. On board the SSBN's, the time of reception of test messages and the character error rates are recorded automatically.

The analysis process to establish system performance consists of four steps. First, the transmitter site data are processed to provide a list of the test messages that were transmitted and that should have been received by the SSBN. Second, the SSBN data are compared with this list to assign a measured character error rate to each transmitted message. Third, these error rates are converted to a probability of successful message reception using the relationship illustrated in Fig. 2 (derivation of the relationship is described below). Finally, statistics are kept on the probability values, and an estimate is made of the probability of successful delivery of controlling orders to the strategic forces by the communications system. This test methodology is outlined in Fig. 3.

The equation used to transform character error rate values into a probability of successful message reception was developed by empirically determining the relationship between the measured error rate and the probability of receiving a phonetic-letters-spelled-out word in error. The derived word error rate, R, was used to determine the theoretical probability of correctly receiving a message composed of N words transmitted three times. This relation is given by the following formula:

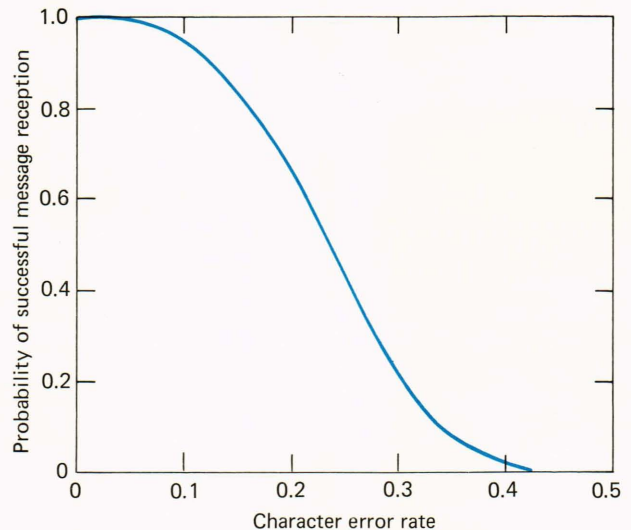$$\text{Probability of successful message reception} = (1 - R^3)^N.$$

Figure 2 — The probability of successful message reception versus character error rate. The relationship is shown between the successful reception of message orders and the character error rate of the technical test messages that are used to determine the probability of reception of a successful message.

PRESENT TEST AND EVALUATION PROGRAM

The initial evaluation of the high frequency component of the submarine broadcast was carried out successfully in the Pacific Fleet area in 1972. This test and evaluation technique has since been used to evaluate both tactical and strategic shore-to-ship broadcasts and ship-to-shore network performance. The main test program has been expanded so that it now includes a continuous evaluation of the performance of all communications links that support command and control of the Naval strategic forces.

In the late 1970's, the Navy deployed computer-controlled digital communications systems having improved performance and additional capabilities, resulting in a change in the test methodology to take advantage of performance information now directly available from these systems.

In a typical radio Teletype transmit signal format for these systems, as illustrated in Fig. 4, each char-
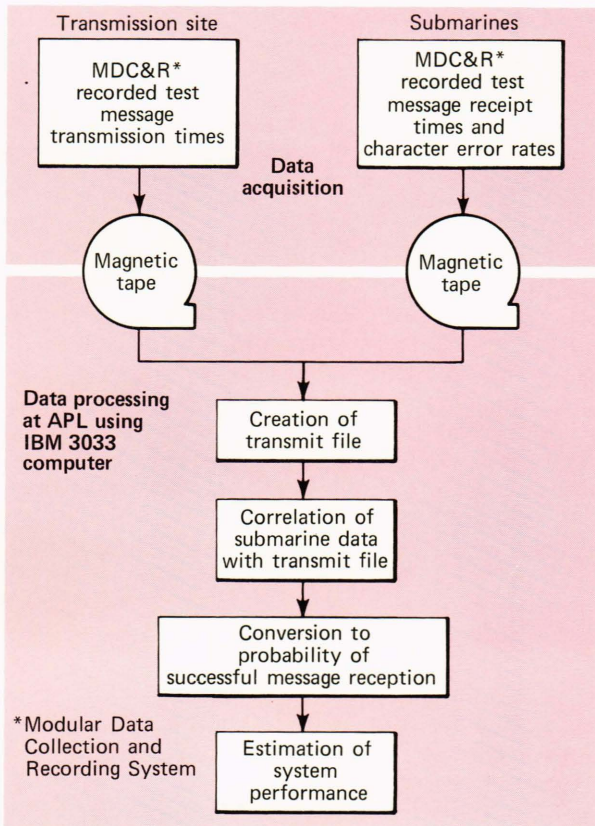
Figure 3 — The communications system test concept. An outline is shown here of the test methodology developed to determine the probability of delivering standard message orders to nuclear-powered Fleet ballistic missile submarines.

continuous output of reception parameters at each submarine receiving system. This output, which is recorded by the Modular Data Collection and Recording System, provides a data sequence from which the synchronization status (in or out of synchronization) and stop-bit error rate are obtained. The synchronization status tells if the receiver has acquired the transmitted signal and is used to determine if a message order could have been received. For periods when the system is in synchronization (transmitted signal acquired), the stop-bit error rate is used to determine if a received message would have been sufficiently free of errors to allow for the execution of message orders. This information is obtained at least every 75 seconds or as often as every 15 seconds when there is a change in the synchronization status.

The relationship between the stop-bit error rate and the probability of successful message reception is illustrated in Fig. 5. The curve in Fig. 5 was derived by empirically determining the relationship between the measured stop-bit error rate and the probability of receiving a phonetic-letters-spelled-out word in error. The derived word error rate is then converted to a probability of successful message reception.

The time period being evaluated is continually segmented by the analysis process into lengths representative of the time required to transmit message orders, and a probability of successful message reception is computed for each segment. Statistics are kept for these results, and an estimate of system performance is made.

ADDITIONAL APPLICATIONS

There have been three extensions of this basic test and evaluation concept. The first was to extend the evaluation program to include low-data-rate, infrequently transmitted links. Because of the length of operational messages (in the tens of minutes) and the infrequent exercising of these links, technical test messages could not be transmitted. Also, there was no continuous output of synchronization status and error rate available for measuring the channel quality. Thus, in order to test the links, exercise messages must be sent and determined to have been either correctly or incorrectly received by the receiving platform. The results of the tests are reported to the evaluation agency to derive an estimate of the probability that controlling orders can be successfully delivered.
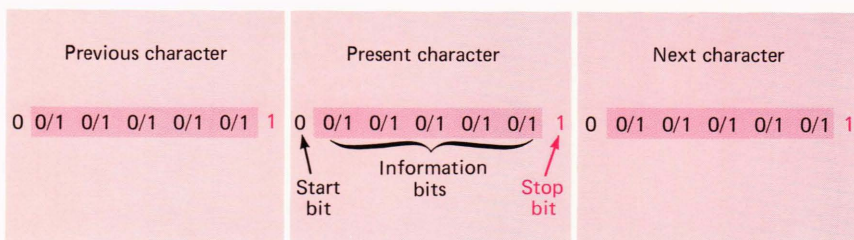
acter is composed of 7 bits. The bits are transmitted by modulating the radio transmitter to provide one of the following forms of transmission: on/off keying, frequency shift keying, or phase shift keying. In any case, only two distinct transmit conditions are recognized. These conditions are most frequently described in digital terminology as 0's and 1's. In Fig. 4, it is shown that a Teletype character consists of a combination of seven 0's or 1's. The first element (bit) is called the start bit and is always 0, the next 5 bits are coded to represent a character, and the 7th bit is called the stop bit and is always 1. Since the stop bit should always be received as a 1, its error rate can be used easily to characterize reception performance.

The processor-controlled communications system used for strategic submarine broadcasts provides a

Figure 4 — A typical radio Teletype transmit signal format is comprised of a sequence of characters. Each character is composed of a start bit (always 0), 5 information bits (coded to represent a character), and a stop bit (always 1).
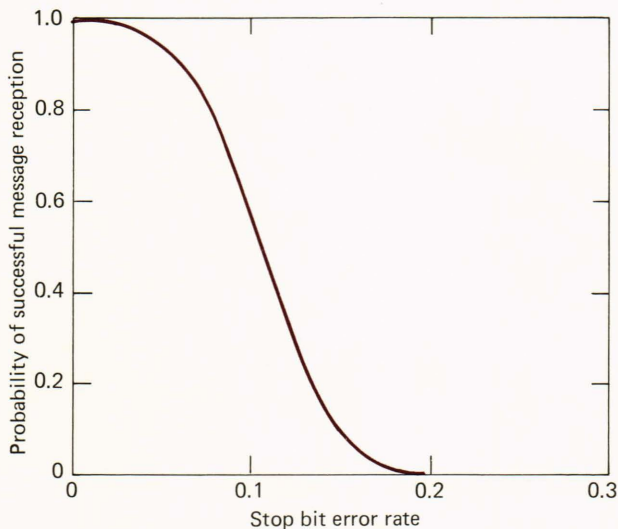
Figure 5 — Probability of successful message reception versus stop-bit error rate. This figure shows the relationship between the successful reception of message orders and the stop bit error rate used for the continuous evaluation of circuit quality.

The second application is use of the basic test and evaluation methodology to supply data necessary to determine an estimated service coverage by geographical area in terms of the distribution of character error rates or the probability of successful message reception.

The third extension of the original methodology is to use the measured communications parameters to determine whether the performance of a communication system is meeting its specifications. In this case, the expected parameters are used as a baseline against which the actual measured parameters are compared.

FUTURE PLANS

As new communications systems are deployed by the Navy's strategic forces, they will be tested in this continuing evaluation program. To provide for a smooth transition as new systems are developed, the Laboratory maintains liaison with the developing agencies. This liaison will ensure that the new generations of computer-controlled communications systems will (a) provide the necessary continuous output of circuit parameters and (b) provide the Laboratory with sufficient lead time to adapt as necessary its test and evaluation equipment or the software used to evaluate the measured data.

CONCLUSION

The major thrust of this communications systems test and evaluation program has been to emphasize measuring the quality of the message, the end product. The measurement of intermediate quality factors such as signal-to-noise ratio or the time distortion of a demodulated radio Teletype signal have been de-emphasized. The continuing evaluation program is primarily a system performance evaluation tool and secondarily a system diagnostic tool.

By concentrating on measuring whether a message is likely to be received, either by evaluating the message directly or by transforming some measured error rate to a probability of successfully receiving a message, the program has provided the Navy with results that are reliable, timely, and usable in developing a communications capability to meet its needs.

While this test and evaluation concept was developed in response to a need to determine the performance of broadcasts serving strategic forces, the concept is also applicable to other communications systems such as tactical broadcasts or two-way point-to-point links. Adaptations of the original concept have been used to perform such testing.

NOTE

[1] As indicated, tests of Naval communications systems have been conducted during normal peacetime operations. Estimates of system performance in a wartime environment have been provided using the communications network model (discussed in a companion article in this issue), which uses the measured results obtained in a peacetime environment for calibration purposes and extrapolates them to a hostile environment.