Knowledge-Based Operation and Management of Communications Systems*

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ABSTRACT

Expert systems techniques are being applied in operation and control of the Defense Communications System (DCS), which has the mission of providing reliable worldwide voice, data and message services for U.S. forces and commands. Thousands of personnel operate DCS facilities, and many of their functions match the classical expert system scenario: complex, skill-intensive environments with a full spectrum of problems in training and retention, cost containment, modernization, and so on. Two of these functions have been the subject of research programs at Lincoln Laboratory over the past two years, sponsored by Rome Air Development Center and the Defense Communications Agency respectively, namely 1) fault isolation and restoral of dedicated circuits at Tech Control Centers and 2) network management for the Defense Switched Network (the modernized dial-up voice system currently replacing AUTOVON). An expert system for the first of these is deployed for evaluation purposes at Andrews Air Force Base, and plans are being made for procurement of operational systems. In the second area, knowledge obtained with a sophisticated simulator is being embedded in an expert system. The background, design and status of both projects will be described.

1. INTRODUCTION

In order to maintain peak performance despite the fact that no electronic equipment can run indefinitely without degradation or failure, all communication systems must provide for detecting and correcting deficient operation. The growing technical disciplines of Network Management and of "AO&M" (Administration, Operation and Maintenance) in the telecommunications industry reflect the substantial payoffs that can be obtained by prompt and careful attention to these factors, keeping network performance and revenues continually close to peak design capabilities. A number of efforts have been undertaken to provide automated aids for human operators carrying out these functions, and in recent years artificial intelligence techniques have been pursued in the attempt to achieve consistently high performance despite operator skill and experience limitations [1].

For military communication systems, the motivations for continually maintaining high network performance are slightly different. For one thing, chronically tight defense budgets tend to limit communications expenditures to the bare minimum, and adequate support of military requirements can only be achieved if these minimum systems can be kept tuned to their peak capability. Another significant difference is that military communication systems are precedence-oriented: in times of emergency or network damage the best achievable service must be provided to the most critical users, even if this requires preemption or denial of service to less essential users. Moreover, military operators and technicians tend to be young and inexperienced compared to their civilian counterparts; this increases the risk that military networks may not be at their best, and creates even greater need for automated aid systems.

The purpose of this paper is to briefly describe two ongoing projects which which are developing Expert Systems techniques for assisting military personnel in maintaining peak performance of military voice and data communications systems [2,3,4,5]. One project addresses Technical Control, which is the process of isolating faults and restoring service on critical dedicated circuits. The other project addresses Network Management for the worldwide voice system called the Defense Switched Network; this is the process of

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allocating and controlling network resources to assure reliable service for high-precedence dial-up users, despite failures or congestion in major portions of the network.

2. THE EXPERT TECH CONTROLLER

Work has been in progress since FY86 on the Expert Tech Controller (or ETC), an expert system for assisting humans in performing circuit fault isolation and service restoral at military Tech Control Facilities (TCFs) [2,3,4]. A worldwide network of some 400 TCFs performs these functions for more than 61,000 dedicated circuits operated by the Department of Defense (DoD) for facilities or users who must have full-time connectivity because they are continually active, or because their mission requires instant communications in the event of emergency. Such circuits include, for example, high-usage long-haul trunks for the military switched voice network; dedicated circuits linking the Pentagon and the White House with military force commanders; and data links joining various essential computer systems.

ETC was initially implemented with ART (trademarked acronym for Automated Reasoning Tool, an Expert System shell produced by Inference Corp.), on a Symbolics 3640 computer. This approach yielded precisely the advantages that one hopes for under such conditions: we were able to rapidly prototype a system that performed circuit fault isolation, focusing our attention on acquisition and understanding of knowledge in the problem domain rather than expending energy on the writing of software tools and facilities. By being able to frequently come back to the domain knowledge sources (senior NCOs at a major TCF, the 2045th Communications Group at Andrews Air Force Base, Washington, DC) with working software implementations of the knowledge they had given us in our previous visit, we were able to sustain a high level of enthusiasm and cooperation.

As ETC's knowledge base grew its operation became slower and slower, however, especially during resets. Our analysis indicated that the generality and power of the ART design brought along much overhead that was not needed for the particular kinds of problems ETC had to deal with. Accordingly, we decided to reimplement the system entirely in ZetaLISP, the native language of the Symbolics machine. The resulting performance was entirely satisfactory; ETC moved along at about the rate at which a skilled human operator would reason about the problem in hand. Development and extension of the system

knowledge base continued steadily thereafter until about mid-FY88, when it was decided to suspend further development of ETC and transfer our efforts entirely to an advanced project called MITEC (Machine-Intelligent Tech Controller), described below.

3. ETC FUNCTIONALITY

1,000 or more circuits pass through a typical TCF, where the Tech Controllers can access them for test, patch and re-route purposes via banks of manual patch panels. Having been gradually implemented over a number of years, these circuits involve a potpourri of equipment types and vintages, and the acquisition of fault isolation skills for all the commonly used variations can require years of practice.

The basic mission of Tech Controllers is to insure that the circuits passing through their TCF are continually available and operating at peak efficiency. Whenever a circuit outage occurs, Tech Controllers rapidly isolate the faulty segment and patch around it with spare facilities, or with facilities preempted from lower-precedence circuits, to restore service. At this point a repair order is issued for the appropriate repair service to find and fix the specific equipment failure. During a normal working day at the Andrews Air Force Base TCF there are typically several of these circuit outage problems in progress at once. On a less urgent basis, Tech Controllers endeavor to minimize failures by performing routine quality assurance testing on working circuits, in order to identify and correct incipient problems before they occur. The workload resulting from all these duties is substantial, and the actual personnel complement on board at a TCF is typically somewhat below the authorized level; moreover, two-thirds of these are likely to be trainees. Consequently there is great interest in the possible application of Expert Systems techniques for raising personnel work efficiency by allowing them to work at higher skill levels.

The initial objective for the ETC development was to create a concept demonstration model showing how an Expert System could perform in the TCF environment. The design goal for ETC was the capability to isolate the causes of the majority of the normal kinds of problems (e.g., no signal, receiving garble, excessive retransmissions) on the many types of circuits (e.g., voice, data, teletype, digital) using the wide variety of communication links (e.g., land lines, HF radio, microwave, satellite, etc.) between TCFs. The initial concept

assumed an "air gap" between the problem-solving logic and the communications equipment: ETC directed the measurement and data-gathering actions of a human operator via CRT displays, and the human supplied the requested information to ETC via mouse and keyboard. The problem-solving logic applied by ETC reflected knowledge obtained from skilled human practitioners. Graphics displays and text messages aided the novice operator in visualizing and understanding the fault isolation processes. Upon isolating the faulty circuit segment, ETC would supply instructions for the operator on how to patch around it. Finally ETC would complete the paperwork items required of human operators under normal circumstances, namely a log of the isolation and restoral procedures completed and a repair order for fixing the faulty equipment.

By early FY88 the indications were that the concept demonstration goals of ETC had indeed been achieved. It was estimated that ETC's knowledge base encompassed the circuit, device and fault types involved in more than half of the normal daily work load at Andrews. Planning was begun for a follow-on system development that would "close the air gap" by allowing ETC to directly access the communications and test equipment, find the fault, and electronically patch around it. This system would exploit modern remotely-controllable communications, access and test equipment typical of that in use in the commercial telecommunications industry, and gradually being installed in military facilities. This new system, called MITEC (Machine Intelligent Tech Controller), would be targeted for introduction in the field on the same time scale as the modern communications and test equipment.

At the present time, further development of ETC has been suspended and the design of MITEC is in progress. A communications testbed is being assembled to serve as a development and demonstration environ-environment for MITEC. This testbed represents two modern TCFs joined by digital trunk circuits in the 24-channel industry standard 1.544 Mbps DS1 format (often referred to as a T1 carrier). Each TCF has a group of local users, and each is controlled by its own Expert System. The testbed includes voice and digital user terminal equipment; modems and telephone lines; first- and second-level multiplexers; a DACS-II cross-connect switch for T1 trunks; and HLI 3200 test access switches provided with HLI 3701 and 3705 test sets. In-service and spare circuits are provided at several levels,

and remotely-controlled matrix switches can select the desired configuration. The initial goals for MITEC are to demonstrate fault isolation and service restoral on all the circuit and trunk fault variations that are possible on the testbed, which will represent the majority of situations likely to be encountered at modernized TCFs. These processes will proceed with no air gap, that is, with no direct human inter-actions other than keeping the operator informed via screen messages, and giving the operator the go/no-go decision authority before a suggested circuit patch is actually executed.

4.   SIMULATION AND EXPERT SYSTEMS FOR DSN NETWORK MANAGEMENT

The DSN (Defense Switched Network) is currently being implemented as a modern replacement for the AUTOVON (Automatic Voice Network) system that was originated in the 1950s to provide reliable voice service for military commanders in CONUS and overseas. The service concept in both cases is direct-dial long-distance service between authorized telephones on military installations, carried on government-leased or -owned trunk circuits (which are a major category, by the way, of the dedicated circuits handled by the Tech Control Facilities discussed above).

A key feature of the system is a five-level precedence and preemption structure (Routine, Priority, Immediate, Flash, and Flash Override), in which a call being placed by a higher-precedence user can automatically preempt lower-precedence calls in progress if necessary. Another feature of the system is that it is engineered to provide good service (i.e., low blocking probability) for precedence users at the lowest possible cost. Basically, this means that the number of expensive long-distance trunks between pairs of switching nodes is made as small as possible. Routine users, who generate at least two-thirds of the normal peacetime traffic, therefore get significantly higher blocking probability on AUTOVON/DSN than civilian customers experience on the commercial networks.

The baseline requirement for Network Management in this Spartan environment is to do the best possible job of providing non-blocking service to precedence users in the face of traffic overloads, equipment failures or other disrupting influences. In the antiquated AUTOVON system the provisions for network management were minimal; in some cases certain manual actions were possible (such as re-programming switches to block calls to a failed switch), but for the

most part the response to network problems was to dispatch repair crews and wait for service to be restored. A key feature of the DSN program is the replacement of the aging, limited AUTOVON switches with modern computer-controlled equipment that offers far greater Network Management power and flexibility. Two immediate problems arise in seeking to take advantage of this power: 1) there is no pre-existing body of DSN Network Management knowledge, and 2) it appears that the tasks of the DSN Network Manager will be complex and demanding, creating serious manpower training and retention needs.

The ongoing program in DSN Network Management at Lincoln Laboratory [5] has two main thrusts in addressing these problems: creating NM knowledge by experimentation with a powerful DSN simulation, and embedding this knowledge in an Expert System capable of advising less-skilled human operators as well as retaining a corporate memory of NM knowledge through personnel transfers and returns to civilian life.

5.   THE CALL-BY-CALL SIMULATOR (CCSIM)
A large Fortran program has been developed which simulates all the DSN activities relevant to NM on a call-by-call basis. Its host computer is a Sun 3/260 work station, which typically simulates faster than real time (depending upon the size and complexity of the network being simulated). A CCSIM run is initialized with the topology and connectivity of the network under study, typically all the backbone switching nodes in a theater-wide DSN (i.e., Pacific or European), and is also provided with the matrix of average busy-hour routine and precedence traffic levels for each source/destination pair in the network. Random number generators initiate calls in accordance with statistical models of caller behavior, with averages matching the given matrices. Every event associated with each call is modelled, including all route selection processing, blocking and preemption events at source, destination and intermediate nodes, and user retry behavior. As the simulation progresses the experimenter can apply overload and fault conditions, and he can select and apply network management control actions from an available repertoire which, in the real world, would be transmitted to switch control computers throughout the network and would cause modifications in the way switches process subsequent calls.

CCSIM produces two classes of output information: concise local statistics reports for each network node, identical to the 5-minute

summaries continually transmitted to central authority by real switches in the field, and exhaustive reports of the details of the simulation run. The former constitute a set of "soda straw" views of the network that will be the only statistics information available to DSN network management personnel at theatre headquarters (the Area Communications Operations Center or ACOC), while the latter provides the experimenter with omniscient understanding of what really happened during the run. Such precise and complete information is obtainable because CCSIM actually tracks every simulated call through its complete history, from birth to death.

The process of Knowledge Engineering that is currently ongoing with CCSIM involves the initiation of specific damage or overload events during a run, followed by analysis of the switch reports to discern patterns and indicators that a network manager at the ACOC could have recognized as evidence of the existence of the particular fault condition. The experimenter then chooses a candidate NM control command and applies it to CCSIM, analyzing both the switch reports and the comprehensive statistics for indications that the control is successfully minimizing performance degradation caused by the fault condition. This knowledge engineering process is quite painstaking, involving many repetitious experiments to achieve statistical regularity as well as to understand the effects of parameter variations in both the damage and control commands. Preliminary results of this experimentation are described in [5].

In the near term, a separate effort has been undertaken to create an ACOC operator training system to develop personnel skills to meet the immediate needs of manual network management of the DSN, which is currently in the process of implementation. This training system will use the CCSIM to produce 5-minute reports as inputs to the existing operator console and support equipment. A training supervisor will set up CCSIM runs with representative fault conditions, and the operators will learn to recognize the statistical signs of trouble and to select and apply control actions, which will then be reflected in the ongoing operation of CCSIM.

6.   THE NETWORK MANAGEMENT EXPERT SYSTEM (NMES)
An Expert System is being implemented to alleviate the DSN NM personnel training and retention problems. The long-range goal of this effort is to aid the ACOC NM personnel by performing pattern recognition on the

incoming stream of 5-minute switch reports to detect problem conditions, then to recommend NM control actions to overcome the problems -- in short, to embody and make available the store of NM knowledge developed through experimentation with CCSIM, and also to be augmented over time with the accumulated experience of the operations personnel. In the near term, the NMES is being integrated with CCSIM to form an interactive engineering tool in which the expert system can diagnose and correct problem conditions in the simulated network. This integrated system will be used in advancing the knowledge development for network managment, as well as for other types of network engineering.

The Network Management Expert System has been implemented with ART, running in a Common LISP environment on a Sun 3/260 work station. The nature of the NM problem seems better matched to the ART structure than was the Tech Control environment, and it seems likely that the implementation will stay in ART for the time being. The NM problem is much more a matter of scanning collections of slowly-varying facts to see whether rules are satisfied, in contrast with the sequential nature of circuit fault isolation exercises. Moreover, while ETC had to be reset after every fault diagnosis in order to clear its world of all the schemata that were created while proceeding down the various unsuccessful and successful lines of inquiry, NMES can avoid time-consuming resets because, once it is turned on, it maintains an essentially continuous view of its problem domain.

A group of NMES software modules called "monitors" process the incoming switch reports from CCSIM, each watching for a particular pattern suggested by our knowledge engineering activity. An abstract state model of the network is maintained, including the nature and location of each of the problem indicators noted by the monitors. Higher-level modules analyze the network state, postulate problem conditions, and then confirm or reject the conclusions over successive 5-minute intervals. Another module consults the knowledge base of NM control actions to correct confirmed problems, and sends instructions to CCSIM to implement the controls at all the switch locations specified. An additional module watches the effects of the controls applied, both to determine whether the controls or parameters should be modified, and to remove the controls as soon as the problem condition goes away. Each knowledge module in the expert system has its own set of monitors that can be turned on or off, to scan the switch reports for patterns of interest.

7. SUMMARY

Military communications systems are subject to manpower skill, training and retention problems of a quite different order than their commercial counterparts, and are thus a fertile field for the development of knowledge-based software support systems. Moreover, commercial automated aid systems tend not to be applicable to the military problems, because of such differences as precedence and pre-emption capabilities. Two problem areas have been selected for concept validation development of expert system techniques addressing military needs, namely Technical Control and Network Management. Both systems have been developed to the point of substantial functionality, and appear likely to lead to transfer of the technology into the field.

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