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DESIGN AND USE OF A DATA LINK
FOR HIGH-ENERGY PHYSICS EXPERIMENTS

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ABSTRACT

The use and operating characteristics of a data link between small on-line computers (PDP-5's) and a large batch-processing computer (Control Data 6600) is described. This link was constructed to permit access to the large central computer during the operation of high-energy physics experiments. This access allows the processing of portions of the experimental data on a nearly real-time basis. Certain design restrictions were imposed by the nature of the CDC 6600 and its normal mode of use.

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INTRODUCTION

At the Lawrence Radiation Laboratory, the typical small computer used on-line with a high energy physics experiment carries out several important tasks. It controls data acquisition from various sources associated with an experiment. It records the data onto magnetic tape. It monitors the operation of the data-acquisition equipment, does simple calculations to indicate the progress of the experiment, and generates meaningful but simple displays. Normally, the detailed analysis of the data is beyond the capacity of the small computer and must be performed by the large general-purpose computers. In our case, the small computers are PDP-5's and PDP-9's; the large computers are two Control Data 6600's. In the past, the transfer of recorded data between the small and the large computers has been accomplished by means of hand-carried reels of magnetic tape. This normally results in delays of hours or days until the analyzed data is returned to the experimenter. In some cases, this is satisfactory; in other cases, the efficient operation of the experiment requires a faster return. To provide a means of immediately processing a portion of the acquired data and to immediately return to the experimenter the results of this analysis, the data link described in this paper has been constructed. It provides direct communication between the 6600 and the small on-line computer. Figure 1 shows the basic components of the link.

SYSTEM DESIGN

The design of such a link involves considerations that are different from one laboratory environment to another. They also depend on the type and frequency of usage that the link receives, as well as the other computer loads. Because of the complexity of the overall data-processing and computer system, some of the questions that affect the final design cannot be answered until the link is at least partially operational. For example, the computer center normally operates with a batch-processing mode. This includes analysis of the data on the tape reels from the remote experiment. It is difficult to predict whether the

data processing that is originated by the link is in place of, or in addition to, the processing of data that would otherwise have come in on the hand-carried reels of tape. This is important, because the large computers are usually operating at, or close to, their capacity. It is difficult to predict how much of the data analysis program will be written and tested before the experiment begins. Often such software cannot be completed until the idiosyncrasies of the data-acquisition components are discovered. This may tend to limit the usefulness of the link during the early part of an experiment.

For these and other reasons, the following ground rules were set up as the basis for the design of the initial system:

1. Modifications to the existing 6600 hardware and to its operating software system were to be minimized. Since the link would originate a very small part of the 6600 throughput, interference with the normal batch-processing mode could not be tolerated.

2. The data-link system would be used only for partial analysis of the complete set of data from the experiment. It was to occupy the attention of the 6600 for only a very small percentage of the time. The number of periods during which the 6600 services the link would be limited to several per hour.

3. Delays of up to several minutes in answering the request of a small computer for access to the 6600 were to be tolerated. These delays are required to allow the efficient meshing of the remote computer jobs with the normal batch-processing load. On the other hand, turn-around times of a few minutes are entirely satisfactory for nearly all experiments.

4. The remote small computer was to retain the responsibility for the complete recording of all raw data accumulated by the experiment. The data link should be used only for partial analysis of the data. The 6600 should not be burdened with

the task of raw-data recording. This reduces the volume of data the link is required to handle. It also means the experiment carries on if the 6600 system is temporarily out of service.

In addition, it was decided that the initial implementation of the link should be accomplished with the minimum expenditure of time and effort necessary to produce a reliable and usable system. It was felt that if the initial operation proved to be successful, then further effort could be expended later to expand the system in accordance with the lessons learned during initial operation.

One of the pertinent features of the 6600 is its lack of a hardware interrupt feature (i.e., the provision for an externally applied signal to automatically cause a specified response of the machine). One way to overcome this deficiency is to dedicate one of the 6600 peripheral processors (PP's) to periodically scan the condition of the external signal, and to program the PP to have the desired response to this signal. Unfortunately, dedication of a PP to such a purpose inevitably lowers the throughput of the 6600 for other jobs. To avoid this drawback, a plan was devised wherein the computer operator is used as the dedicated scan device in place of the dedicated PP. The operator is alerted each time communication between the 6600 and remote computer is to be effected. He has the power to initiate the analysis program in very nearly the same manner as if it were a normally submitted batch processing program. This strategem immediately satisfies the goal of minimizing the modifications to the 6600 system software. It also has the desirable feature that the regulation of the use of the link is under operator control. It answers possible objections that the use of the link might be abused at the expense of the batch jobs, since the operator can adjust the relative priorities between those tasks and jobs from the link. If in the future the link receives a sufficiently high volume of use to justify it, a more sophisticated and automatic form of interrupt may be designed.

A further result of the scheme described above is that the electrical activation of the link is always done by the 6600 rather than the remote computer. Naturally, the programs on both computers must be coordinated, but the 6600 program is, in effect, the master. The 6600 program calls upon the remote computer, via the link, to transmit data, and the 6600 program alerts the remote computer, via the link, to receive the analysis results.

SOFTWARE CONSIDERATIONS

Data are transmitted by the remote computer over the link with the same format as it uses to record the data onto magnetic tape. Therefore, essentially the same Fortran analysis program can be used both for data transmitted over the link and for data inputted by means of magnetic tape. The 6600 software system permits allocation, at program execution time, of the device called by a Fortran Read or Write statement. By changing a single control statement in the object program deck, such calls may be assigned to a magnetic tape unit or to the data link. This means that the major portion of the analysis programs can be debugged without using the link. In case of link failure, processing of data on the tapes is still possible.

The analysis program resides on one of the 6600 bulk storage devices, usually a disk. When the operator receives a link service request, he causes the program to be loaded from the disk into the central processor core. The program then initiates repeated requests for data records from the link, until it is notified via the link that all the records have been sent. The program then initiates a transfer of the results of the analysis via the link back to the small computer. When this is finished, the program exits, and its entire core space is released for other jobs.

HARDWARE CONSIDERATIONS

The hardware was designed with the following considerations in mind:

1. Data transfer rates of the order of 100,000 12-bit words per second would be considered satisfactory. Higher rates have some

advantages, but are not necessary to use the 6600 efficiently or to cope with the volume of data expected to be transferred over the link.

2. The link will usually operate in an environment of electrical noise owing to spark chambers, accelerators, etc. It was therefore felt that the hardware should be designed to have a high degree of error-detecting and correcting ability in order to relieve the computers from the task.

3. The design should be of modular form to permit expansion of the system by adding remote stations and to permit the use of various models of remote computers.

4. The cost should be the minimum necessary to provide the required reliability.

Ordinary twisted-pair telephone lines were chosen as the transmission media for the link. They have the advantages of low cost and availability between the points of interest. Thirty such lines are dedicated for link uses. Two sets of 12 lines each allow the 12-bit words to be transmitted in bit-parallel mode in either direction. Other lines are used for various control applications.

A simple parity-checking type of error detection was not deemed sufficiently powerful for coping with the expected types of errors. Since all 12 lines concerned with the transmission of a 12-bit word are coupled with the same electrical noise field, there is a high probability of encountering errors involving several bits of the same word. Instead, the error checking is done by an echo method. The receiving station retransmits each word back to the sending station. The sending station compares the returned word bit-for-bit with the word originally sent. If no errors are detected, the next word is sent. In case of a detected error, the same word is repeatedly sent until it experiences an error-free transit, or until it is concluded that the link is inoperative. A round trip between the 6600 and the 184-inch cyclotron takes about 12.5 μsec. This limits the data rate to about 80,000 words per second (1 megabit per second). The echo method also solves the problem of synchronizing two independent computers, each running independently

with its own clock.

Under typical operating conditions, the measured raw-error rate is approximately one error in 10^7 words. These errors were all corrected after one or more retransmissions. The rate at which errors undetectable by the hardware are generated is as yet unknown.

OPERATIONAL DETAILS

Connections to the 6600 are made via one of its data channels. The link interface is a logic module called a synchronizer, similar in nature to the synchronizers used with disks, tape transports, and other pieces of peripheral equipment. Communication of data and control information is organized in a similar way to the exchange of information between a peripheral processor and any other synchronizer. Commands are issued in the form of function words, which always travel from the 6600 towards the PDP-5 and, in most cases, evoke a response in the form of a status word. The status word travels from the PDP-5 toward the 6600, and carries information concerning the response of the remote computer to the function-word command.

Before an actual transfer of data can take place, checks must be made to guarantee that the programs in the large and small computer agree on the direction of data transfer, the amount of data involved, and its format. This is accomplished by means of the function and status words. Since these words are largely initiated and interpreted by software, the meaning of the conversational exchange can be altered to meet future changes in the 6600 operating system, or to cope with different types and configurations of remote computers. If the two programs in the two computers are unable to reach an amicable agreement within a specified time, the job is aborted and the operators at either end are notified by their respective computers. Jobs may also be aborted by unrecoverable errors and complete lack of response by one terminal or the other.

STATUS OF THE LINK

At present, the complete link system, including the hardware system and the software routines for both the large and small computers, has been tested over a telephone link of about 4000 feet. The system is in the process of being connected to a physics experiment. This will constitute the first actual operation of the link.

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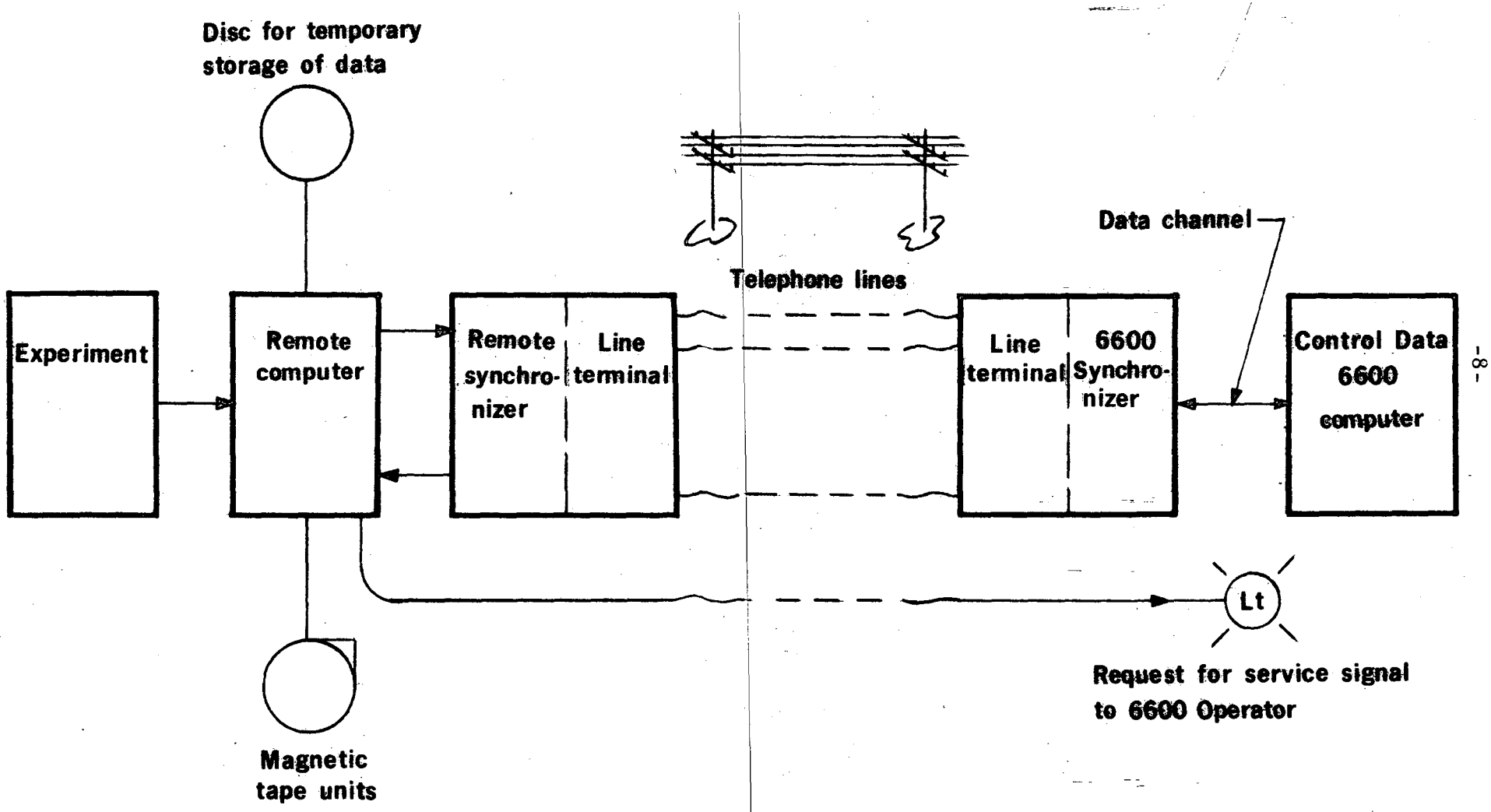
Disc for temporary storage of data
Telephone lines
Data channel
Experiment
Remote computer
Remote synchro-nizer
Line terminal
Line terminal
6600 Synchro-nizer
Control Data 6600 computer
Lt
Request for service signal to 6600 Operator
Magnetic tape units

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