DOCUMENT RESUME

ED 057 575 EM 009 415

AUTHOR	Singh, Jai P.; Morgan, Robert P.
TITLE	Educational Computer Utilization and Computer Communications.
INSTITUTION	Washington Univ., St. Louis, Mo.
SPONS AGENCY	National Aeronautics and Space Administration, Washington, D.C.
REPORT NO	M-71-7
PUB DATE	Nov 71
NOTE	101p.
EDRS PRICE	MF-$0.65 HC-$6.58
DESCRIPTORS	*Communication Satellites; *Computer Assisted Instruction; *Computers; Cost Effectiveness; *Educational Specifications; Educational Technology; Time Sharing

ABSTRACT

As part of an analysis of educational needs and telecommunications requirements for future educational satellite systems, three studies were carried out. 1) The role of the computer in education was examined and both current status and future requirements were analyzed. Trade-offs between remote time sharing and remote batch process were explored as were trade-offs between on-campus minicomputers and shared centralized facilities. 2) An analysis was made of the various aspects of computer communications including the nature of communication terminals and the facilities for data-communications. 3) The use of communications satellites was examined for providing telecommunications for computer applications, with the emphasis on high-powered satellite systems involving small, interactive earth-terminals. The report concludes that what is needed to satisfy computing requirements is relatively high-power dedicated educational satellites capable of operation with a large number of small earth terminals. Although such a development would require a pooling of a large percentage of educational telecommunications users, the economies of such a system appear to be attractive compared to terrestrial-based communications for distances greater than 70 miles. (JY)

ED057575

WASHINGTON UNIVERSITY

Memorandum No. 71-7

November, 1971.

EDUCATIONAL COMPUTER UTILIZATION AND COMPUTER COMMUNICATIONS

Jai P. Singh

Robert P. Morgan

WASHINGTON UNIVERSITY / ST. LOUIS / MISSOURI 63130

EM 009 415

ED057575

PROGRAM ON APPLICATION OF COMMUNICATIONS SATELLITES
TO EDUCATIONAL DEVELOPMENT

WASHINGTON UNIVERSITY

Memorandum No. 71/7

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
OFFICE OF EDUCATION
THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL OFFICE OF EDUCATION POSITION OR POLICY.

October, 1971

EDUCATIONAL COMPUTER UTILIZATION AND COMPUTER COMMUNICATIONS

Jai P. Singh
Robert P. Morgan

This research is supported by the National Aeronautics and Space Administration under Grant No. Y/NGL-26-008-054. This memorandum is primarily for internal distribution and does not necessarily represent the views of either the research team as a whole or the National Aeronautics and Space Administration.

SUMMARY

This memorandum consists of three major parts. First, the role of computers in education is examined and both current status and future requirements are analyzed. Then, an analysis is presented of the various aspects of computer communications which includes discussion of the nature of communication terminals and the facilities for data-communications. Finally, the use of communications satellites is examined for providing telecommunications for computer applications, with emphasis on high powered satellite systems involving small, interactive earth-terminals. The memorandum is a major component of an analysis of educational needs and telecommunications requirements for future educational satellite systems, being performed under a grant from NASA's Office of University Affairs.

Computers are currently being used in education for a variety of purposes, e.g. instruction, research, administration, information retrieval and career guidance at a variety of levels; elementary, secondary, higher and vocational education. A previous memorandum in this series has considered computer-based instruction in some detail. Overall computer utilization has grown rapidly in the U.S. with the last ten years. At the elementary and secondary school level, the primary use appears to be for administration whereas for higher education, utilization is divided roughly equally among research, instruction and administration. In 1967, the President's Science Advisory Committee recommended an average of approximately 20 minutes of computer time per student per year as a goal for computer usage in higher education. However, at the start of the 1970's about one-half of the nation's colleges and universities are lacking in computer services which seems to represent an inequitable distribution of computing resources.

There are a number of alternatives for providing computer services to computer-poor institutions. Remote time-sharing and remote batch processing, two modes of computer access, offer some advantages for small and remotely located institutions. These include less expense and less long-term commitment than owning an equivalent on-campus facility, less management and administrative supervision and better quality and variety of services than a small institution could manage on a dedicated basis. Trade-offs between remote time sharing and remote batch processing are explored as are trade-offs between on-campus minicomputers and shared centralized facilities.

Educational computing systems which involve use of telecommunications may be classified as either centralized or distributed-intelligence computing networks. In the centralized network, actual computing and maintenance for all users are carried out at a central location whereas in a distributed network, computing can be carried out at more than one location. Both types of networks can be implemented on either an inter- or intra-institutional basis. The memorandum explores various aspects of computer communications of importance in resource sharing, i.e. the sharing of computer power between "have" and "have not" institutions, including multi-access interactive computer communications, remote batch

processing and inter-computer communications. The latter two categories involve two way machine-to-machine communication at relatively higher speeds.

An examination of existing telecommunications plant and costs reveals that unless communications costs are significantly lowered, they could become the most expensive part of large-scale computing networks and long-distance information transfer. The cost of a telephone line appears to have been roughly constant over the past decade whereas the cost of computers has been dropping at about 25% per year. This may seem surprising in view of advances in such technologies as cable, millimeter waveguides, microwave, etc. However, the problem is that over 80% of the telecommunications cost is in the local telephone plant and associated switching equipment. New, specialized common carriers such as DATRAN and MCI offer possibilities for economies in this area.

Communications satellites offer certain advantages for interactive multi-access computing and remote batch processing provided that the local telephone switching plant can be bypassed. Small earth terminals colocated at the computing facilities and shared with other services such as ITV can be designed to avoid the high error rates associated with existing switching equipment. Essential cost-benefit analyses remain to be performed.

Because of the long communications circuit length associated with synchronous satellite systems, satellite circuits have a long delay associated with them. Various technical communications schemes are proposed to minimize the effects of this delay. If the system is such that the user must wait for 1.0 second until his keyed in response appears on a display terminal, as would be the case in a Plato-IV type system operating with satellite, the delay involved is clearly intolerable. However, systems in which such "echoing" from the main computer is not intrinsic would appear to be perfectly feasible.

Recent filings by companies before the Federal Communications Commission for commercial domestic satellite systems were required to discuss terms and conditions under which satellite services would be made available for data and computer usage in meeting educational requirements. Of eight applications that were filed, only four responded by spelling out their public service offerings and only one (MCI-Lockheed) explored possible computer usage. Only one proposal (Fairchild-Hiller) contemplates use of frequencies (2.5 GHz) and satellites power levels suitable for use of low-cost earth terminals for interactive communications.

We conclude that what is needed to satisfy computing requirements is relatively high-power (55-60 dBW e.i.r.p.) dedicated educational satellites capable of operation with a large number of small earth terminals. However, such a development would require a pooling of a large percentage of educational telecommunications users. Such cooperation presents major political-administrative-organizational problems. The technical problems appear to be solvable and preliminary communications systems design conclusions are presented in the memorandum. Furthermore, the economies of satellite-based computer communications with small-terminal based interactive interconnections appear to be attractive compared to terrestrial-based communications for distances greater than 70 miles.

TABLE OF CONTENTS

No. Page

Summary ii

1. Introduction 1

2. Computers in Education 3

2.1 Introduction 3

2.2 Current Status Of Computer Utilization And The Requirements For The Future 9

2.2.1 Introduction 9
2.2.2 Utilization At Elementary And Secondary School Level 11
2.2.3 Computer Utilization in Higher Education 20

2.2.3.1 Introduction 20
2.2.3.2 PSAC Report 23
2.2.3.3 Development of Computer Services 25

2.3 Provision Of Computer Services 29

2.3.1 Introduction 29
2.3.2 Modes of User Access 31
2.3.3 Sources of Service 35

3. Computer Communications 40

3.1 Introduction 40

3.2 Multi-Access Computer Communications 44

3.2.1 Introduction 44
3.2.2 Conversational Terminals 45
3.2.3 The Data Stream Model 50
3.2.4 Remote Batch Processing 56

3.3 Inter-Computer Communications 57

3.4 Computer Communications And Existing Telecommunications Plant 60

4. Satellites and Computer Communications 66

4.1 Introduction 66

4.2 The Effect Of Large Propagation Delay On Computer Communications 67

TABLE OF CONTENTS
(continued)

No. Page

4.3 Candidate Satellites. 68

4.4 Providing Small Earth-Terminals Access To Satellite For Interactive Data-Communication. 72

4.5 Economics of Satellite-Based Computer Communications. . . . 78

5. References 80

Appendix A. Information Coding and Error Control 88

LIST OF FIGURES

No. Page

1. Computer Applications in Education 4

2. Development of Computers 6

3. Major Trends In Development Of Computer Usage. 10

4. Adoption Of CAI In Elementary And Secondary Schools. 13

5. Costs Per Student Hour In Introducing CAI In Schools 13

6a. Geographical Distribution of Secondary Institutions Using Electronic Computers 15

6b. Geographical Distribution of Secondary Institutions Reporting Instructional Applications of Computers. 16

7. Information Flow In Multi-Level Information Systems For Education. 19

8. Expenditures On Computer Activities By Institutions Of Higher Education. 21

9. CAI Adoption In Higher Education 26

10. ARPA Computer Network Topology 30

11. Centralized Computing Facility 33

12. Time-Sharing vs. Batch Processing. 34

13. Decentralized or Distributed Computing Network 41

14. Evolution Of Distributed Networks. 43

15. The Data Stream Model. 51

16. FDMA Performance--Number of Accesses vs. $[C/T]_{Dn}$ 74

17. TDMA Performance--Number of Accesses vs. $[C/T]_{Dn}$ 75

18. Random Access (SSMA) Performance--Number of Accesses vs. $[C/T]_{Dn}$. 76

Appendix A:

1. USA Standard Code For Information Interchange (ASCII). 89

2. Generalized Scheme of Two-Dimensional Parity Checks. 92

LIST OF TABLES

No.		Page
1.	Computer Use By Institutions of Higher Education (1966-67)	22
2.	Modes of Computer Access	31
3.	Matrix Of Computer Access And Source Options	36
4.	Keyboard/Printer Terminals (Teletypewriters)	46
5.	Keyboard/CRT	48
6.	Characteristics Of Graphic CRT Terminals	49
7.	Characteristics Of Systems Studied By Jackson and Stubbs	53
8.	Average Parameter Values	54
9.	Mean Values Of Holding Time Components	55
10.	Remote Batch Terminals	58
11.	Common Communication Lines and Transmission Speeds In Use Today	62

EDUCATIONAL COMPUTER UTILIZATION AND COMPUTER COMMUNICATIONS*

1. INTRODUCTION

This memorandum is part of a continuing study of the application of communication satellites for helping to meet U.S. educational needs. First, the role of computers in education is explored. The status of computer usage is examined in elementary, secondary and higher education in terms of instructional, research and administrative functions. The area of computer-based instruction has been explored in a previous memorandum.

An analysis is then presented of the various means of providing computer service. Modes of user access, e.g. non-interactive and interactive, are defined and the advantages and disadvantages of time sharing versus batch processing are described. The possible sources of computer access are presented with particular emphasis on distinctions between services available to universities on campus and those available from off-campus sources. Trade-offs between local mini-computer services and resource sharing among institutions are examined.

With the preceding as background, a detailed discussion is provided of communications aspects of computer utilization. Multi-access computer communication is explored in detail, including examination of hardware (conversational terminals), communications processes (data stream model) and requirements for remote batch processing. This is followed by an analysis of inter-computer communications. The existing physical facilities for computer communications are then examined from the point of view of costs and compatibility, with requirements derived from the previous sections. The entry of specialized common carriers such as MCI and Datran is noted and contrasted with Bell system capability for handling digital information of the kind needed for computer communications.

An examination of the role of communications satellites to identify opportunities for computer-communications has been undertaken. This memorandum places particular emphasis on systems which employ small interactive earth terminals. The effect of the large propagation delay inherent in the long distances involved is considered and recommendations are made for overcoming this delay in certain cases by proper communications systems design. Recent domestic satellite filings are noted and their limitations for computer-communications discussed. The memorandum concludes with considerations of communications systems design and economic analysis of systems involving high-powered satellites and small interactive earth terminals for computer communications. An Appendix presents information on information coding and error control which is of importance in communications systems design.

In this memorandum, we have begun to explore in a substantive way the systems aspects of computer usage involving satellites. Although the first part of the memo on computers in education will be of general interest, the latter part is technical in nature and is primarily the work of one of us,

*The authors wish to thank Mrs. Emily Pearce for the very skillful typing of the manuscript.

Jai P. Singh. The first part of this memorandum has benefitted substantially from the writings of R. E. Levien (Rand Corporation), J. W. Hamblen (Southern Regional Education Board), and M. Greenberger (John Hopkins University). This effort, along with the previous papers generated in the overall satellite-education study, provides essential information for the over-all needs analysis to follow in which a variety of communication media and educational services will be pooled together to provide an integrated set of requirements for an educational satellite system.

ERIC

2. COMPUTERS IN EDUCATION

2.1 INTRODUCTION

Utilization of digital computers in education can be described jointly by the nature of various application--instructional, administrative, research and other such as information retrieval and vocational guidance--and, by the level of the user institution--elementary and secondary schools, and institutions for vocational and higher education. Figure 1 presents a matrix showing various computer applications at various levels of educational institutions and systems.

The instructional applications of computers can either center around the objective of providing instruction about the computer or instruction with the computer. Instruction about the computer occurs in fields such as engineering, business, mathematics, sociology and computer science, in which the computer itself is the subject of study. Levien[1] has subdivided the instruction about the computer in three subcategories: specialist instruction, which serves those prospective engineers, programmers, analysts, and others who will devote their career to some aspects of computing; service instruction, which serves prospective scientists, businessmen and professionals who will use computer tools in their future careers; and survey instruction, which serves all students, who as citizens and consumers will have to be aware of computers' benefits and dangers.

Instruction with computers occurs when the computer is used as a tool to assist the teacher or the learner during the instructional process. The computer may present tutorial or drill material, aid in the simulation or gaming of a complex process, assist in the solution of difficult practice problems, keep track of student progress, or give review tests or examinations while differentiating curriculum material to fit individual needs and providing immediate attention to individual responses. Active teaching by computer is known by many names: Computer-Assisted Instruction (CAI), Computer-Managed Instruction (CMI), Computer-Based Instruction (CBI), or Computer-Assisted Learning (CAL). CAI is the most popular and common name used to define the man-machine relationship in which a man is a learner and the machine is a computer-system. Two-way communication exists between them, with the objective being human learning and retention. During instruction, the only humans in the system are the learners. CAI is a small subset of the situations involving instruction with computer and is reserved for those particular learning situations in which a computer contains a stored instructional program designed to inform, guide, control and test the student until a prescribed level of efficiency is reached.[2] CAI/CMI/CBI have been the subject of a previous memorandum[3] specifically addressed to the examination of their current status, future prospects, and the man-machine communication that is involved; hence, this memorandum shall exclude any detailed discussion of them.

Administrative applications of computers in educational institutions/systems are many and varied. Computer can provide assistance in the management of finances, personnel, programs and facilities--the areas of concern to the administration of any educational institution and system.[4,5] Computerized financial operations include general accounting, payroll,

	Instructional Applications of Computers					Administrative Applications of Computers				Research Applications of Computers								Library Applications		
	Instruction about Computers			Instruction with Computers						Research on Computers			Research with Computers							
	Specialist Instruction	Service Instruction	Survey Instruction	Computer Assisted Instruction/ Computer Based Instruction/ Computer Managed Instruction	Computer Assisted Problem Solving	Computerized Financial Operations	Computerized Personnel Management	Computerized Program Management	Computerized Facility Management	Hardware Oriented Research	Software Oriented Research	Research on Theory and Science of Computing	Number Processing	Symbol Processing	Data Processing	Event Processing	Picture and Sound Processing	Circulation Automation and Computer Aided Cataloguing	Computerized Indexing and Retrieval	Computer Aided Vocational Guidance
Elementary Schools				X		X	X	X	X						X					
Secondary Schools			X	X	X	X	X	X	X						X					X
School District						X	X	X	X						X			X		
Vocational Schools	X		X	X		X	X	X	X						X					
Community Colleges	X	X	X	X	X	X	X	X	X						X					X
Colleges	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		X	X	
Universities	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	

Figure 1. Computer Applications in Education

inventory record-keeping, budget preparation, and cost-analysis. Computerized personnel management can be used for registration, grade reporting, grade recording, and keeping records of student attendance. Computer applications centering around the institution's or system's programs, both in instruction and research, concern the proper scheduling of classes to satisfy student demands, faculty availability, and facility utilization. Administrative applications related to the instructional program include the study and evaluation of teaching methods, curriculum, and instructional materials.

Research application of computers can be subdivided into two categories: (1) Research on Computers, and (2) Research with Computers. Research is the first academic activity that was influenced by the computer; and the computer itself is very much a product of campus-based research activities during World War II. The first digital computer is credited to Professor Howard Aiken of Harvard University who developed an electro-mechanical digital computer called Mark I (or Automatic Sequence Controlled Calculator) in August 1944. The first all-electronic computer, ENIAC (the Electronic Numberial Integrator and Calculator) was also a product of campus research; it was developed at the Moore School of Electrical Engineering, University of Pennsylvania. The first stored-program computer designed was the EDVAC at the University of Pennsylvania. A major contribution to digital computers in the early days was made by MIT where the scientists and engineers conceived and built a memory that used "cores" of magnetic material to store elementary information and to provide access to data and programs fast enough to match the high calculating speeds of the arithmetic unit.[6] The descendants of that device now provide storage for virtually every digital computer. From these and a few other university-based research activities came the basic concepts of computer design that still underlie the industry. The "tree" in Figure 2 indicates how these machines led to the development of a variety of later computers.[7] However, the leadership of the universities in this field, particularly in the hardware aspects of it, while of tremendous importance, was brief. The cost and difficulty of developing full computer systems became too great and caused many university-based groups to abandon their activities.

Today the research on computers can be divided into three categories: (1) Hardware; (2) Software; and (3) Theory and Science of Computing. Some research on hardware still occurs on campus, but it is usually concerned with advanced technologies or special components as opposed to the development of full computer systems. One apparently striking exception, as Levien[5] notes, is the ILLIAC IV computer whose design was contemplated at the University of Illinois. However, this activity was initiated at the Westinghouse Research Laboratory, and actual construction is being carried out by the Burroughs Corporation.

Software research is concerned with the design of programming languages and the programs that translate them into machine language, design of programs called operating systems (control of resource allocation and job assignment, clerical tasks, and monitoring), and the design and development of on-line time-sharing systems. Much of the early development in the time-sharing field took place on university campuses.[8] Notable examples are the CTSS (Compatible Time-Sharing System) at MIT, which was the first general purpose time-sharing system based on the IBM 709 computer and

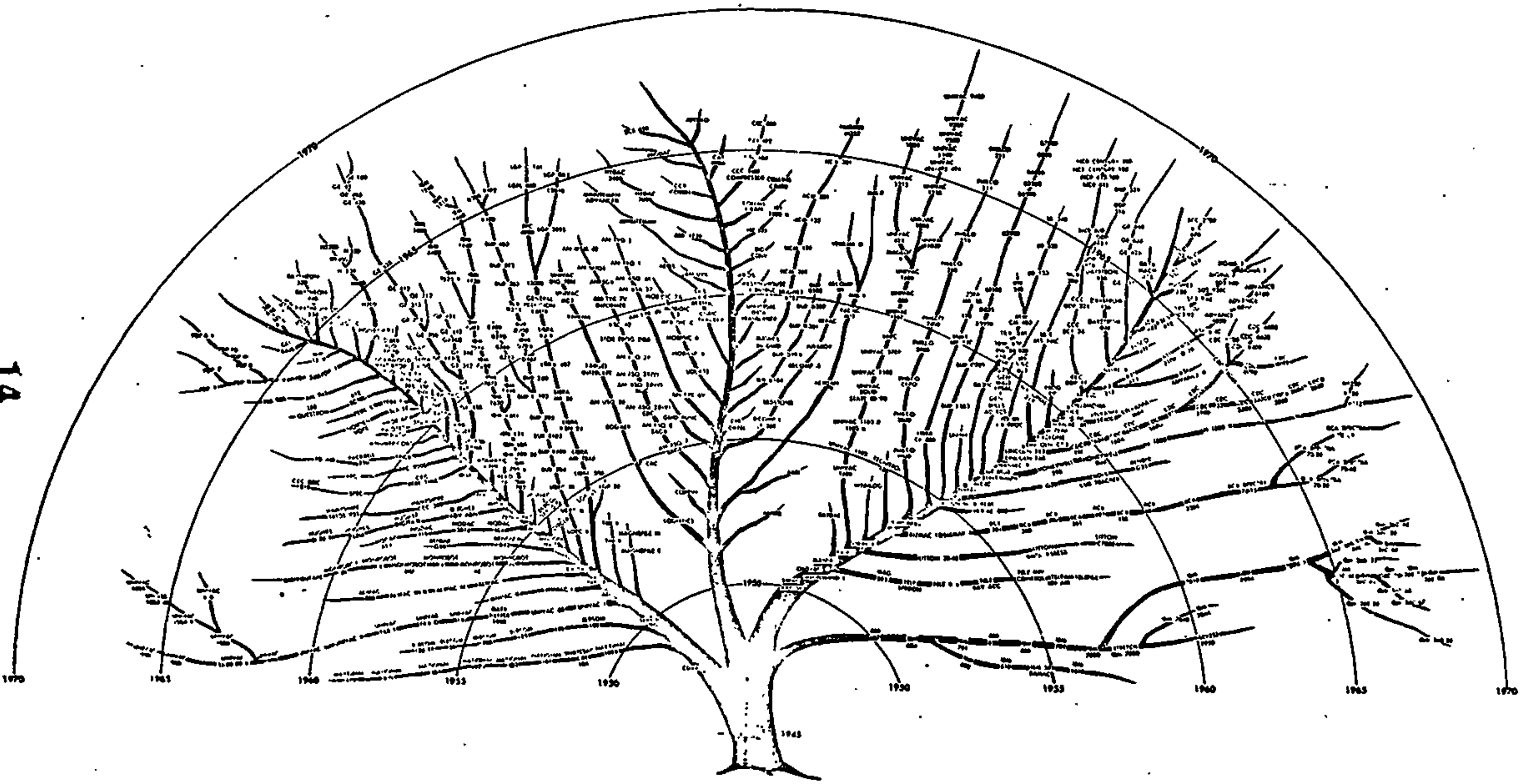


Figure 2. Development of Computers [Ref. 7]

whose experience has been reflected in all subsequent developments; the Dartmouth system, which formed the basis for General Electric's commercially available service, and the University of California-Berkeley system, which formed the basis for Xerox Data System's time-sharing computer system. However, once again the leadership role in this area has changed and it is expected that the university's role will once again fade as industry gains comparative advantage.

Research related to the theory and science of computers has been concerned both with deepening understanding of the theory of computers and with extending the range of their abilities. According to Levien[5], the former is an activity in which the university can be expected to play the major role as it has much in common with mathematics, logic and philosophy; the university is generally unconcerned with the design and use of actual computers. The latter, however, has a character similar to software development and may be seen as an activity growing out of that. Research related to language translations, artificial intelligence, manipulating graphical information, and proving theorems in plane geometry, etc. falls in this category.

Research with computers is concerned with number and information processing (symbol, data, picture, sound, and events). The first users of computers on campus were, of course, those with large numeric problems, principally physicists and engineers. Today the spectrum of computer users seeking solution to numeric problems has become diversified; economists, statisticians, psychologists, sociologists, chemists and environmental scientists have also been relying on the computer for solutions. By providing increased efficiency in solving routine problems and extending man's ability to solve previously unsolvable problems, the computer has freed man to seek out and to understand the nature of experimental results, as well as to refine and advance his products and methods of design.

As far as computer-aided symbol processing is concerned, not long after the first research with computers began, it was recognized that numbers could be reinterpreted as other symbols, and the computer's ability to move, compare and alter numbers could be used to carry out similar processes on letters. Early uses were found for business. However, the universities tapped this power of the computer for initiating machine-translation research programs and these programs have continued to provide increased knowledge of the character and complexity of human languages as well as a repertoire of techniques for language processing by computer.

Another natural area of educational application of the computer's great symbol-processing ability has been the library--for the purposes of indexing and retrieval of books and articles. One must also recognize that it is this very power of symbol processing that has introduced computer to disciplines far removed from engineering and the physical sciences. For example, the computer with all its mechanical persistence and accuracy, allows literary scholars to construct indices for the occurence of words and phrases in manuscripts and assists them in the formal aspects of stylistic analysis. It also assists legal scholars in the search for and study of statutory material.

As Levien[5] points out, numbers and symbols are important not only for themselves but for the facts that they represent. It is one thing to be able to compute the solution of a partial differential equation, another to catalogue occurences of some sequence of letters in a text, and still another to be able to maintain a file of information or facts. The use of the computers to store, retrieve, and assist in the analysis of information representing facts--as a data processor--is becoming more and more common both on and off campus. For example, in the medicine disciplines, there are many records whose storage, retrieval, and analysis by machine would be very helpful--foremost being patient histories.

Another important area of computer-aided research is that of picture and sound processing. Through appropriate devices, visual and aural symbols can be translated into numbers and symbols, which are entered, processed, and then used by the computer to command other devices to produce new visual or aural signals. The computer has gained increased usage in the area of the processing of the pictures returned from metereological and earth resource satellites and lunar probes, interpretation and analysis of X-rays and other diagnostic photographs in medicine, bubble chamber photographs in physics, and simulation of advanced bandwidth reduction techniques for efficient transmission of television pictures. Another area of increasing computer application is the generation of animated films or picture sequences as a means of conveying dynamic information to a human audience. The computer has been used to solve the complex physical equations that attempt to describe global weather processes, the effects of explosion on solid plates, the effect of tidal flow on the dispersion of pollutants in a bay, and the dynamics of bodies in motion under the influence of various gravitational laws.

One further way in which the computer's capacity as a number and symbol processor may be turned to broader application is through use of the symbols and numbers to represent the dynamic interaction of events; the computer then becomes an event processor. There are two forms of this role. In the first, the events are handled entirely internally by the computer. This application is usually called computer simulation. In the second, events processed internally by the computer are linked closely to events occuring outside. This application is called computer control in some cases, computer gaming in some others.[5] The use of computers as an internal event processor for simulation is valuable both for those disciplines concerned with man-made phenomenon (engineering, sociology, business administration, economics) and for certain disciplines concerned with natural phenomenon (physiology, biology, and psychology). Physiologists are already using computers to explore the behavior of neural networks to enhance their understanding of human nervous system.

Another major application of the computer is in the field of libraries, particularly in regional and national libraries and those belonging to colleges and universities. Today, libraries are facing administrative and management problems due to an enormously high rate of growth in the amount and collection of published material as well as the need for information dissemination in a wide variety of media. In this context, there have developed four types of computer-related activities in libraries, different in their level of sophistication and in their implications for the future:

clerical applications, circulation, cataloging, indexing and retrieval.[5,9] They range from applications that are administrative in character, such as the ordering of books and journals, and automation of the cirulation, to those that are related to the information and factual content of the publication, rather than its physical form. In the area of computerized indexing and retrieval, project INTREX at MIT provides some clues to its future.[10] Research in this project is intended to provide comprehensive indexing coupled with a natural, on-line request language to allow users to consult a computer-based file in much the same way they would consult a reference librarian who happened to have memorized the complete library catalogue. Researchers are also thinking in terms of answering questions with facts, rather than references: quoting answers and relevant portions from the text of books instead of referring the inquirer to a bibliographic reference.

An important application of computers in high schools, that does not come under either instructional or administrative applications, is in the area of post-high school career guidance. Frequently the information on which students base their post-high school plans is obtained informally, in a non-systematic manner. In a survey of a better-than-average school district in one northeastern state, graduates one and five years out of high school indicated that guidance and counseling was their most important unfilled need. Additional evidence of the instability of high school students' career planning is well documented in the survey and studies conducted under Project TALENT.[11,12] Today, over ten different systems have been proposed for computer-aided individualized guidance and counseling.[11] A central feature of these systems is a computer library or data base of career and college information along with various methods for its retrieval. One career guidance system asks the student about his interests and post-high school plans and then lists possible jobs and/or colleges matching his characteristics. Then the student may request additional information about any of these possibilities.

2.2 CURRENT STATUS OF COMPUTER UTILIZATION AND THE REQUIREMENTS FOR THE FUTURE

2.2.1 Introduction

We are roughly twenty years into the computer age. During this time, the use of computers has expanded rapidly. In 1950, there were about a dozen computers installed in the United States. They were served by fewer than a thousand programmers, analysts, and operators. By 1960, the number of installations had grown to almost 6,000 and the information-processing field had attracted several tens of thousands of skilled personnel. There are now almost 80,000 computers in the United States; their manufacture, service, and use employ between 500,000 and 1 million persons.[5] And this phenomenal growth is expected to be even more rapid during the coming twenty years. Some estimates see the number of computers doubling by 1975, and doubling again by 1980 (see Figure 3a). However, forecasters are unable to predict the future of computing over more than a few years; the growth so far has been so great that it has generally exceeded the most optimistic estimates.

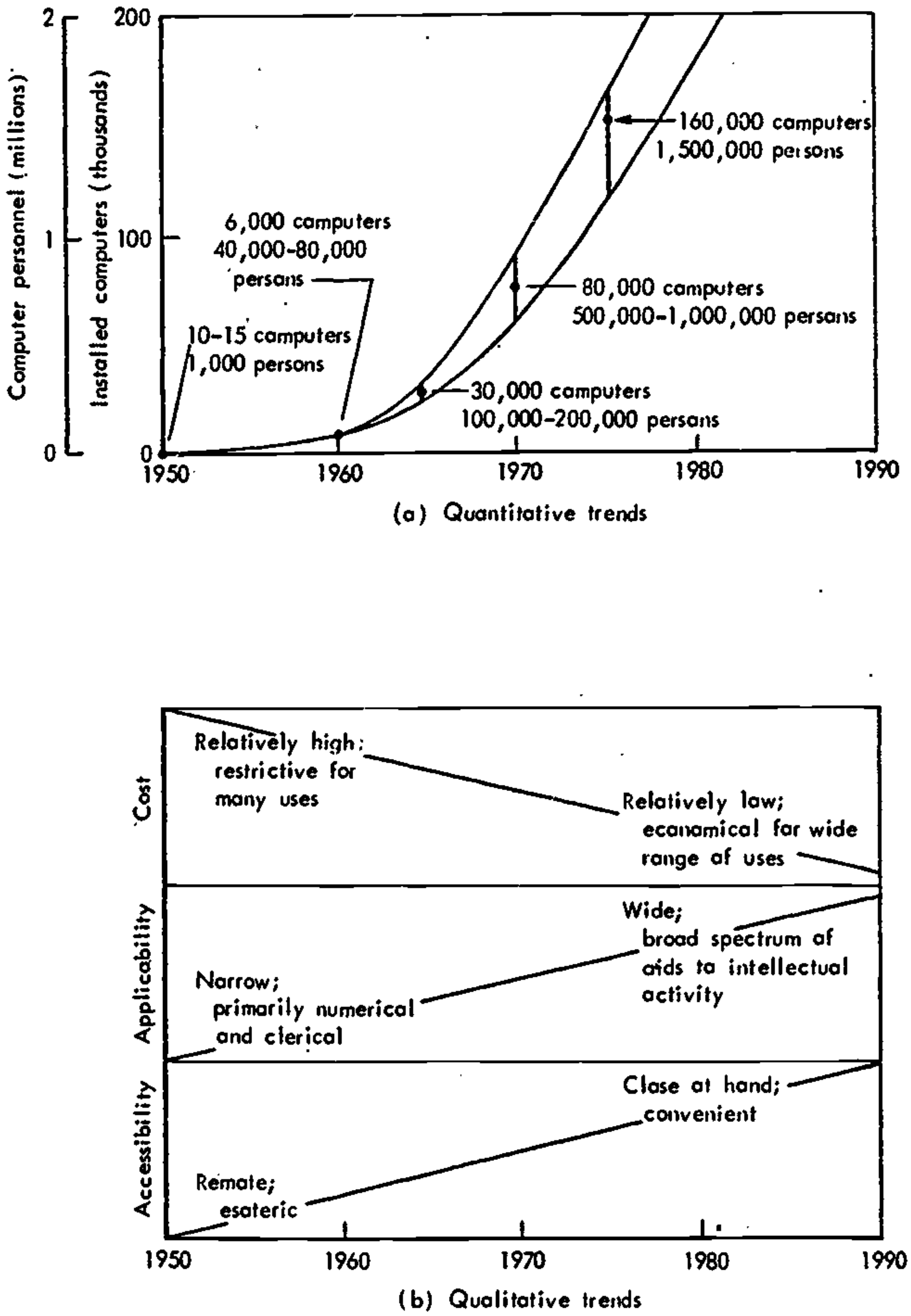


Figure 3. Major Trends In Development of Computer Usage [Ref. 5]

But the quantitative changes in computer use tell only a part of the story. Dramatic qualitative changes are underway as well. As Levien[5] puts it, we are now experiencing the transition from an era in which the computer was an esoteric tool to one in which the computer will be an everyday necessity--the transition from, what can be viewed as the parochial era, during which computer usage was expensive and justified only for a narrow class of tasks (numerical and clerical in nature) to a universal era, in which, for an extremely broad range of applications, computer usage will become economical and, consequently, will be widely applied to tasks that now seem infeasible. Major qualitative trends in the development of computer usage are summarized in Figure 3b.

The requirements or need for computer utilization and applications in education are derived from two considerations: (1) the needs of the society, and (2) the cost-effectiveness of computers relative to alternative ways of performing a similar task. For example, the need for instruction about computers is strictly derived from the needs of society, in which the computer is widely used, for specialists trained in its use and for a populace aware of its properties. Consequently, the future of instruction about the computer and, consequently, the computer applications in this area, depend on society's future needs for computer specialists, users, and literates. Here the relative cost of computer use (as compared with other modes of instruction) in instruction about the computer is not a major question, because the computer must be a part of such instruction in most cases, just as expensive laboratory equipment is an essential part of teaching in the physical and biological sciences, engineering and medicine. Various other computer applications listed in Figure 1, such as instruction with computers, administrative applications of computers, library applications, etc., become attractive when they possess some advantage over alternative modes of performing similar functions. The advantage may be that it is more effective, or less costly, or some combination of both (including less effective, but also less costly).

Some of the computer applications in education have the potential to change education significantly; their immense processing power could be used to keep track of things like student progress, give individual review of tests and examinations, aid in the simulation and gaming of a complex process, aid in the circulation and accounting of and retrieval of information in large libraries, and present tutorial or drill material based on individualized needs and objectives--things that would be impossible to do in the conventional way. In this section, the extent to which this potential has been realized will be examined and future prospects assessed.

2.2.2 Utilization at Elementary and Secondary School Level

Though much has been written about the role and scope of computer applications in schools,[4,13,14,15,16] little is known concerning the extent of total computer utilization today, particularly at the elementary school level. The potential computer applications at elementary and secondary institutions are related to their instructional programs, management of finances, personnel and facilities, and vocational or career guidance programs (see Figure 1). However, a look at the scattered published literature suggests that administrative use predominates over instructional use.

At elementary as well as secondary levels, Computer Assisted Instruction (CAI) is still in its infancy and has not been able to achieve widespread adoption due to its high cost and the conflict between the organization of the traditional school system and optimal methods for utilizing computer-based instruction.[3] However, a study exploring the future in educational technology, that was conducted using the Delphi technique developed by the Rand Corporation, suggests a 20 percent utilization at the elementary level during the first half of the decade (70's).[17] The study results suggest that Drill and Practice and Tutorial systems will be the first two types to be adopted at all levels, followed by Simulation and Instructional Games Systems. Some doubts have been raised about the adoption of Socratic Dialogue type of CAI systems at the elementary level because the programs are most complex to write and because children at the elementary level have such a limited attention span and wide, shallow interest areas that the depth knowledge that is supposed to develop from such dialogue would not be of much use.

A major issue in the introduction and adoption of CAI is expected to be the cost of the hardware and software, and the availability of quality software in sufficient quantity. It should be emphasized that the communication costs will play a major role in the adoption of CAI in small, and rural schools. Figures 4 and 5 present the adoption of CAI in elementary and secondary schools and costs per student hour in introducing CAI[17] respectively.

Recently a survey of computing activities in public secondary schools (schools with one or more of grades 9-12) was conducted by the American Institutes for Research.[18] Of 12,396 (53.8%) schools that responded to the survey (out of some 23,033 schools), some 3,776 (30.5%) reported using computers for administrative purposes whereas 1,599 (12.9%) schools reported instructional computer use. Overall, 34.4% or 4,259 schools reported some type of computer use. The survey makes it very clear that administrative use predominates over instructional use as in the case of elementary schools. The large proportion of all users are administrative users (88.6%) and administrative only users (62.4%). The correspondingly small proportion of all users are instructional users (37.5%) and instructional only users (11.3%). The preponderance of instructional users are also using a computer for administrative purposes (69.8%) whereas only a small percentage of administrative users have combined any instructional applications (29.6%).

The AIR survey shows increased instructional applications over the past four years. In 1963, Goodlad et al.[16] estimated a total of 300 secondary schools using computers for instructional applications. In a study done in 1966, Bangs et al.[19] surveyed roughly 11,000 public secondary schools in the United States and reported 181 instructional computer users or 1.7% usage. The AIR survey[18] showed that the most popular instructional applications were problem solving and Electronic Data Processing skills. Next in order of popularity were gaming and simulation and computer-assisted instruction. Only some 30.8% of instructional users reported CAI activity among their spectrum of activities. Problem-solving applications were mentioned by some 82.6% of the instructional users. Interestingly enough, guidance and counseling applications were found to be more closely tied

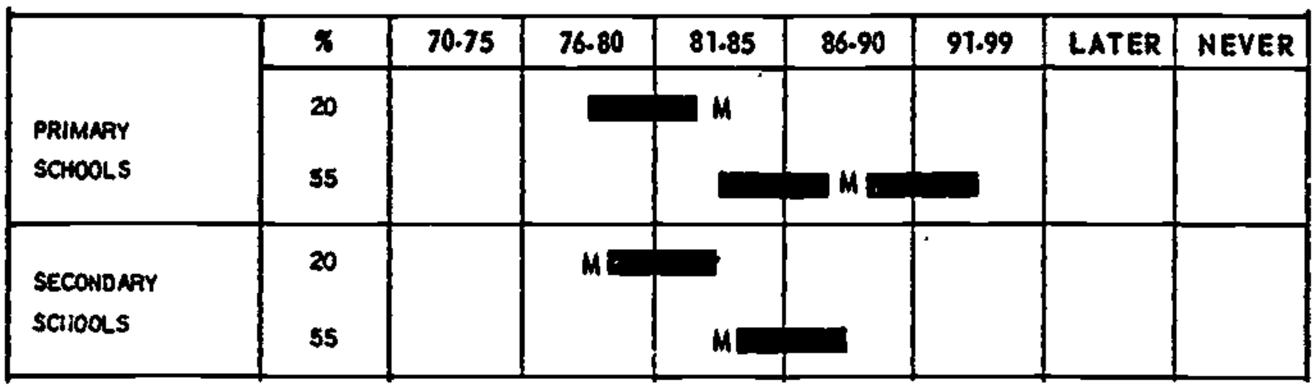


Figure 4. Adoption of CAI in Elementary and Secondary Schools [Ref. 17]

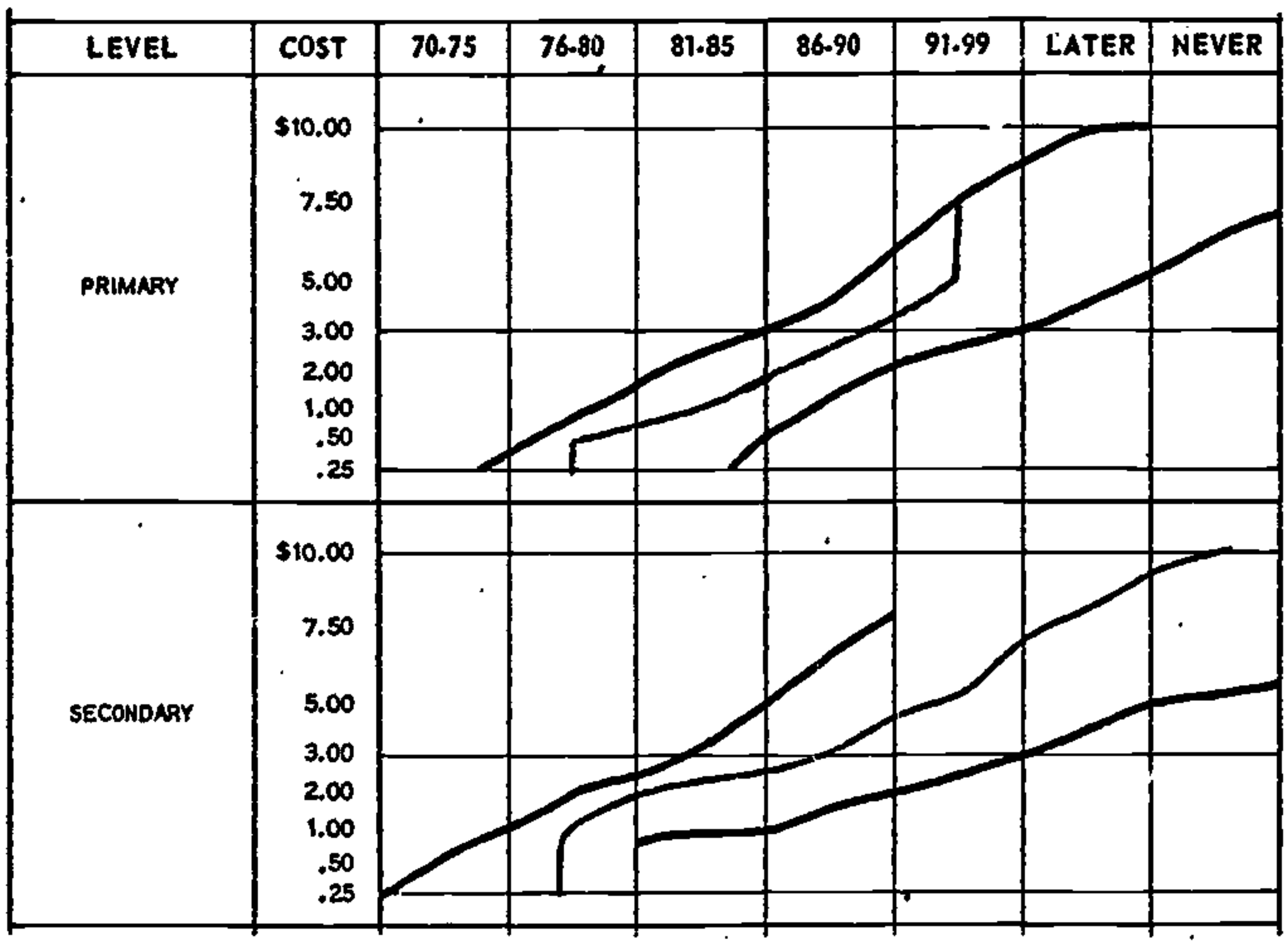


Figure 5. Costs Per Student Hour In Introducing CAI in Schools [Ref. 17]

with the instructional users. Some 15.8% of the schools reporting instructional usage reported guidance applications.

It is not surprising to discover that geographical dispersion of these user schools showed clustering around major metropolitan areas (Figures 6a and 6b). Schools that reported instructional applications tended to be larger in enrollment and teaching staff, to send more graduates to college and junior college, and to be more predominantely comprehensive senior high schools when compared to those schools not reporting instructional applications. The survey[18] showed the 39.8% of computers used by administrative users were leased and 36.1% were used on purchased time basis. Administrative users owned 15.6% of their computers and only 9.7% were provided with donated free time. As opposed to this, 41.3% of the computers used by instructional users were leased, 28% used on purchased time basis, 18.5% were owned and 12.1% used on donated free time.

It was interesting to find out that almost 30% of user schools reported using more than one computer for their applications. The median cost per school for instructional computing was found to be $14,000 but there was considerable variation in the cost. The median percentage of the annual operating budgets for the instructional users as represented by their annual instructional computing budget, was 0.4%. However, this percentage ranged from 0.06% to 20% for individual schools which did indicate that some schools were using computers quite intensively. As far as support of school computer activities was concerned, schools reported that 80% of their computer budget came from local sources. The federal contribution was rather small (6.7%). The most common users complaint was related to the funding--for operation as well as equipment. Insufficient funding was responsible for insufficient access to the computer and/or limited equipment.

In brief, the AIR survey[18] brings forth the fact that over some 65% of the nation's secondary schools have yet to gain access to computer facilities and most of these schools represent those which are not near to major metropolitan areas, are relatively small in enrollment and teaching staff, do not send many of their graduates to colleges and junior colleges, and are not comprehensive senior high schools. However, the survey did show a multifold increase in the number of instructional applications and users in the last four years. One major problem, particularly related to the instructional applications, was that most of the users were operating virtually in isolation from other user groups and there was little communication among them. Each had a limited amount of software available and was not satisfied with its quantity and, in many cases, as well with the quality. This is an area where centralized computing facilities and utilities coupled with some form of compatibility among various computer systems on the market could be of great help.

Recently some educational researchers and planners have put forward the concept of an Educational Information System (EIS) modeled along the lines of Management Information Systems (MIS) for improving the administrative operations and performance of the schools and teachers and making student and teacher performance data readily available for the purposes of the accountability and evaluation of the educational process.[4,13,14] The EIS could be effectively used to establish methods whereby teachers

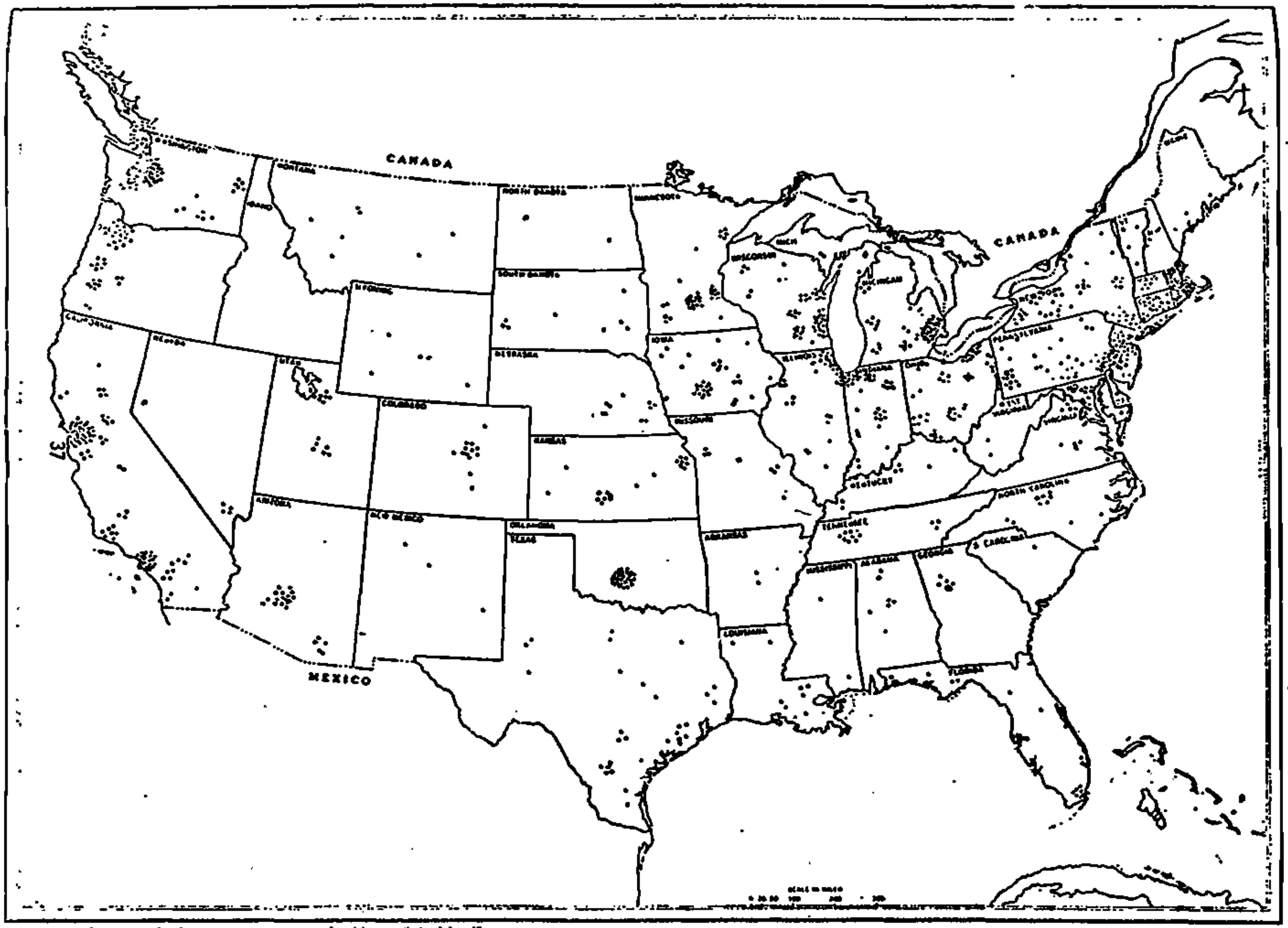


Figure 6a. Geographical Distribution of Secondary Institutions Using Electronic Computers [Ref. 18]

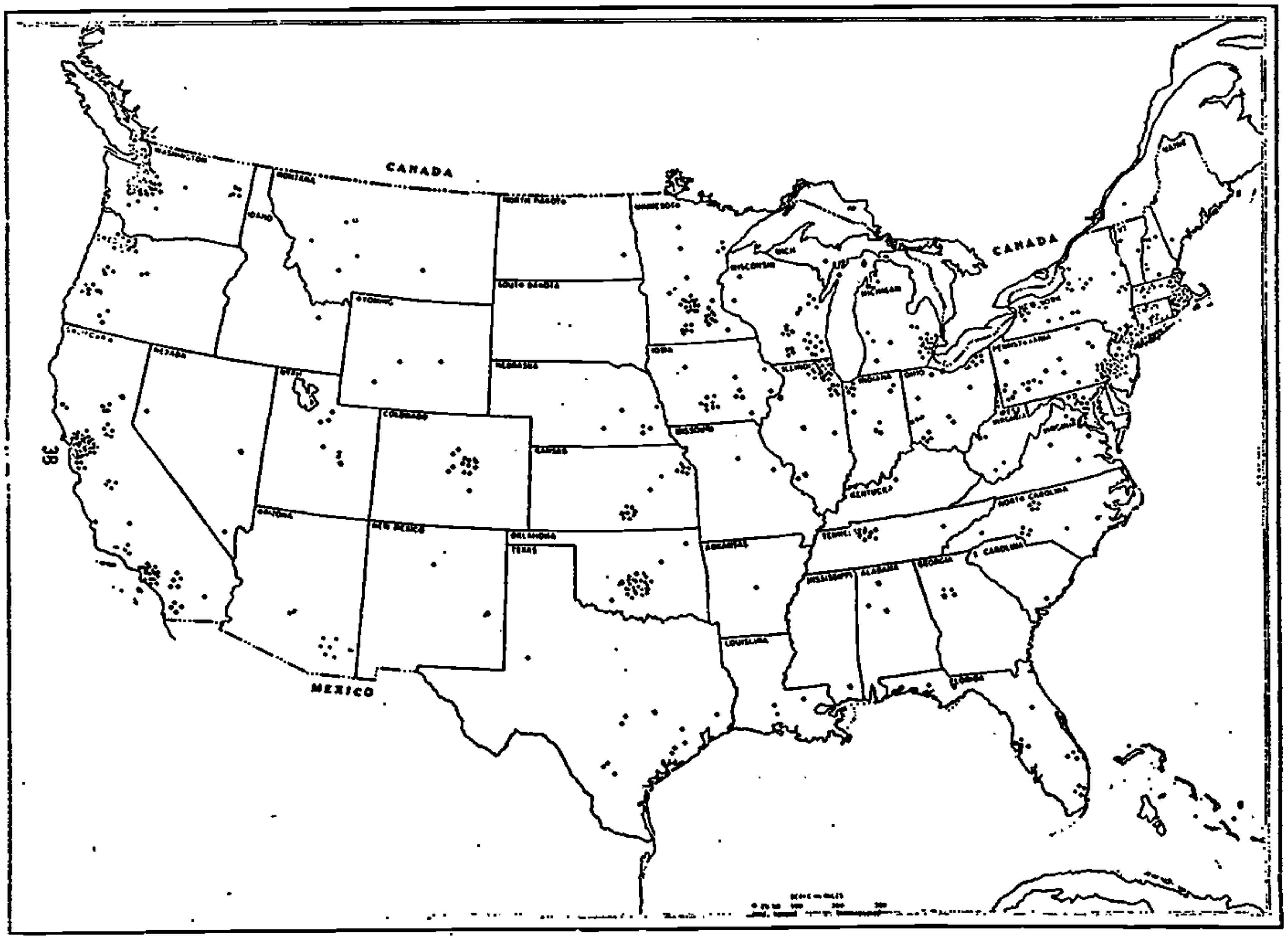


Figure 6b. Geographical Distribution of Secondary Institutions Reporting Instructional Applications of Computers [Ref. 18]

may be held accountable not simply for the method of their teaching, but for the amount and quality of student learning in their classes. The concept of accountability in education seems to be gaining some momentum and approval.[20] EIS seems to have the potential for providing the necessary feedback with the needed speed.

The success or failure of any school depends upon its ability to make decisions on the basis of the effectiveness of its teachers and to determine which teachers are most effective in stimulating various types of learning. In the future, the effectiveness of all educational programs may well be determined by the quality of decisions made in this area. Also, unless the school can determine the most effective types of learning--educationally sound and economically viable--it will not be able to implement essential innovations. Many of the purposes for EIS, as cited by Clayton[13], are administrative, but more than clerical and numerical administrative processing to which computer applications have been limited to date. School administrators and trustees are sometimes at odd on matters of educational policy because each lacks necessary information upon which to base his decisions. Such decisions often involve on-going factors that have financial as well as educational significance.

EIS could be used to provide information upon demand which could form a sound base for intelligent decisions regarding financial and academic policy. For example, the decision to change the method of presenting academic material from several small-class lectures given four times a day to, for example, a single-class lecture given to all students once a day, followed by individual conferences or small group seminars, may be based on sound principles. However, this change may not only alter the number of teachers needed, but also dramatically alter the configuration of classroom buildings and the resources necessary, in addition to increasing the use of the library for independent investigations by students. Failure to account for the economic ramifications of academic decisions, or the inability to forecast accurately the impact of such decisions, could waste valuable resources and result in eventual stagnation of a school's educational program--a luxury that no educational administrator can afford today.

Though no EIS systems exist today in exact sense of the word, a number of educational data systems provide some of the services similar to that of EIS. Coleman et al.[4] have presented a survey of ten such systems. Of the ten systems surveyed, nine of them are implemented on an inter-school basis at the county and state levels. Only one is designed to serve a particular school. Of the nine that have been implemented on an inter-school basis, four are supported by TITLE III USOE funds and three by the Ford Foundation. The largest system belongs to the counties of Macomb, Oakland and Wayne in Michigan and serves some 1,150,000 school children in 93 schools. California seems to be developing a statewide system to serve a potential student population of 2,031,400 in elementary schools and 1,066,529 in secondary schools; however, to date the actual student population being served is 86,000 in elementary schools (4.2%) and 308,000 (28.9%) in secondary schools.

California Total Education Information System is an outgrowth of a pilot project that was conducted in 1960-63 by the Richmond City schools under an NDEA Title V grant aimed at providing integrated data processing in the state of California. The Richmond City schools project was principally a feasibility study involving field testing of a pupil personnel package in five school districts. The conclusions drawn were that "many districts, many schools, and many educators can get together and work out a successful data processing system. They can develop applications that are not only feasible and workable but really efficient...."[21] Today, thirteen regional centers located at Ventura, Sacramento, Fresno, Kern, San Mateo, Contra Costa, Sonoma, San Francisco, Santa Clara, Riverside, San Diego and Los Angeles provide pupil personnel packages to participating schools. The functions of the package include scheduling, attendance accounting, grade reporting, standardized test reporting, guidance counseling, and master file maintenance.[22] The range of prices charged by the regional centers to local districts for pupil personnel packages is given in the table below.[22] (Prices are on a per student basis.)

Secondary		Elementary	
1967-68	1968-69	1967-68	1968-69
$2.50-4.00	$2.90-4.67	$1.00-1.50	$1.25-1.75

In Franklin County (Columbus, Ohio), a similar Total Information Center charges its participating schools for similar services at a rate of $1.00 per elementary school student, $1.50 per junior high school student, and $2.00 for every senior high school student.

Coleman and Karweit[4], Clayton[13] and Blackwell et al.[14], all of RAND Corporation, have very convincingly presented the compelling arguments for bringing about the incorporation of computers in education, primarily at the school level, for storing, manipulating, and retrieving information to meet the information needs of the school systems. The authors feel that such administrative applications hold greater promise for the introduction of computers in schools in near-term future than applications oriented towards providing instruction. The prospects for widespread adoption of computer-based total information systems in education seem to be pretty bright particularly when the demands for accountability in education are getting stronger and the introduction of curricular changes and attempts at new organizational patterns are placing heavy demands on collecting data and evaluating the effectiveness of programs.

Any further discussions of information systems for education is beyond the scope of this memorandum which is primarily oriented towards identifying and evaluating those computer applications that involve telecommunications. Interested readers are referred to Coleman and Karweit's comprehensive treatment of multi-level information systems--their design and implementation.[4] Any forthcoming discussions on telecommunications requirements for such systems will be based on the requirements laid out by Coleman and Karweit.[4] Figure 7 presents the flow of information between the various levels that will be involved in multi-level information systems for education.

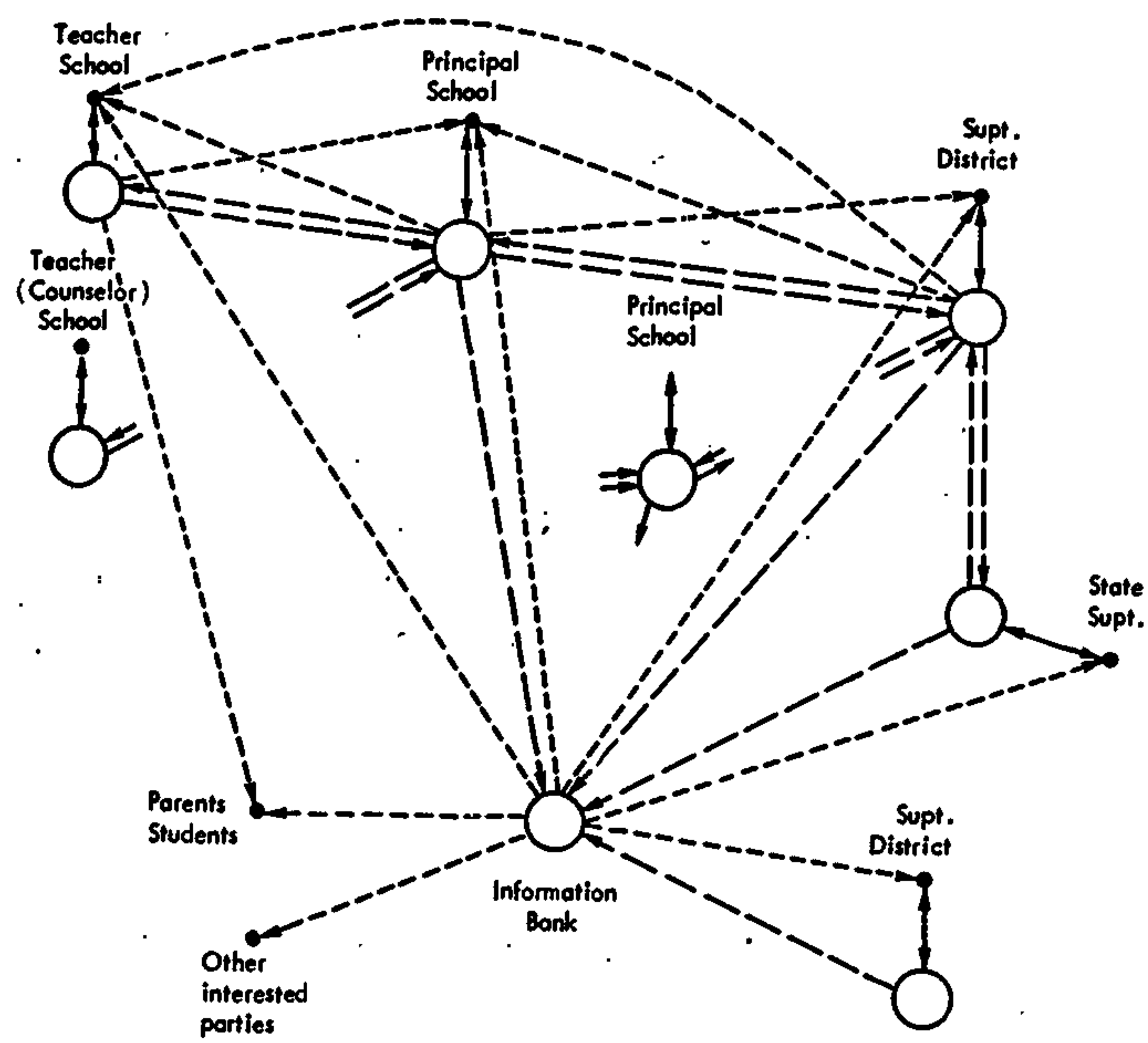


Figure 7. Information Flow in Multi-level Information Systems For Education [Ref. 4]

Centralized information processing systems seem to be very attractive for the implementation of such multi-level information systems that link schools, school teachers, school principals, school district superintendents, students and state superintendents together (access of some participants being controlled to certain files only). Centralized operations decrease duplication of effort and allow more economies of scale in equipment and personnel. Completely decentralized systems do not match the requirements for a multi-level information system that spans schools, school districts and perhaps, in the future, even states. However, a combined cluster-central operation of the type described in another memorandum by Singh and Morgan[3] would generally respond more rapidly to local school administrators and teaching personnel and could also provide other computational services. The final choice at the local school/school district level would depend upon other computational needs and the availability of funding. In Section 3 the modes for access to the computer will be discussed in detail.

2.2.3 Computer Utilization in Higher Education

2.2.3.1 Introduction

Extensive utilization of computers in higher education began in the early 1960's and since then has experienced a striking growth. Figure 8 shows the growth of computer activity in colleges and universities over the seven years since 1962-63, as measured by expenditures. Eight years ago, total expenditures were only $49 million, less than one-sixth of the 1968-69 estimate. The average increase between 1962-63 and 1967-68, the six years for which data is available, is 42 percent. The $235 million expenditure for 1966-67 is a 55 percent increase over the previous year; it increases 22.4% in reaching the 1967-68 total. The increase in 1967-68 does show a downward change, that is, a slowing in the rate of increase; however, Comstock[23] indicates a current 25 percent growth rate for computing expenditures. More computers in the economy means more computer specialists to be trained; computer specialists aside, computer use in research as well as in instruction is growing; and about half of the campuses have yet to begin using computers. As a result, it is reasonable to view Figure 8 not only as a history but as an illustration of a trend that will continue in the future.

Computer use by class of institutions for the year 1966-67 is shown in Table 1 which clearly shows that the computer is ubiquitous only among certain kinds of schools. There are strong inequalities in computer access; students and faculty at many private colleges and universities and even smaller public colleges have yet to enjoy access to a computer. In 1966-67, only 978 of the 2,477 colleges and universities reported using computers. More recent data would show a higher proportion. It has been estimated that the figure was 1,100 in the mid-1968 and 1,255 in mid-1969--44 and 50 percent, respectively.[25,26] In 1966-67, 25 percent of the students (1.7 million) attended colleges and universities without computer facilities. It is estimated that the current figure is about one million students.[25] The situation, however, is not at all alike for public and private education, even when the latter's small enrollments

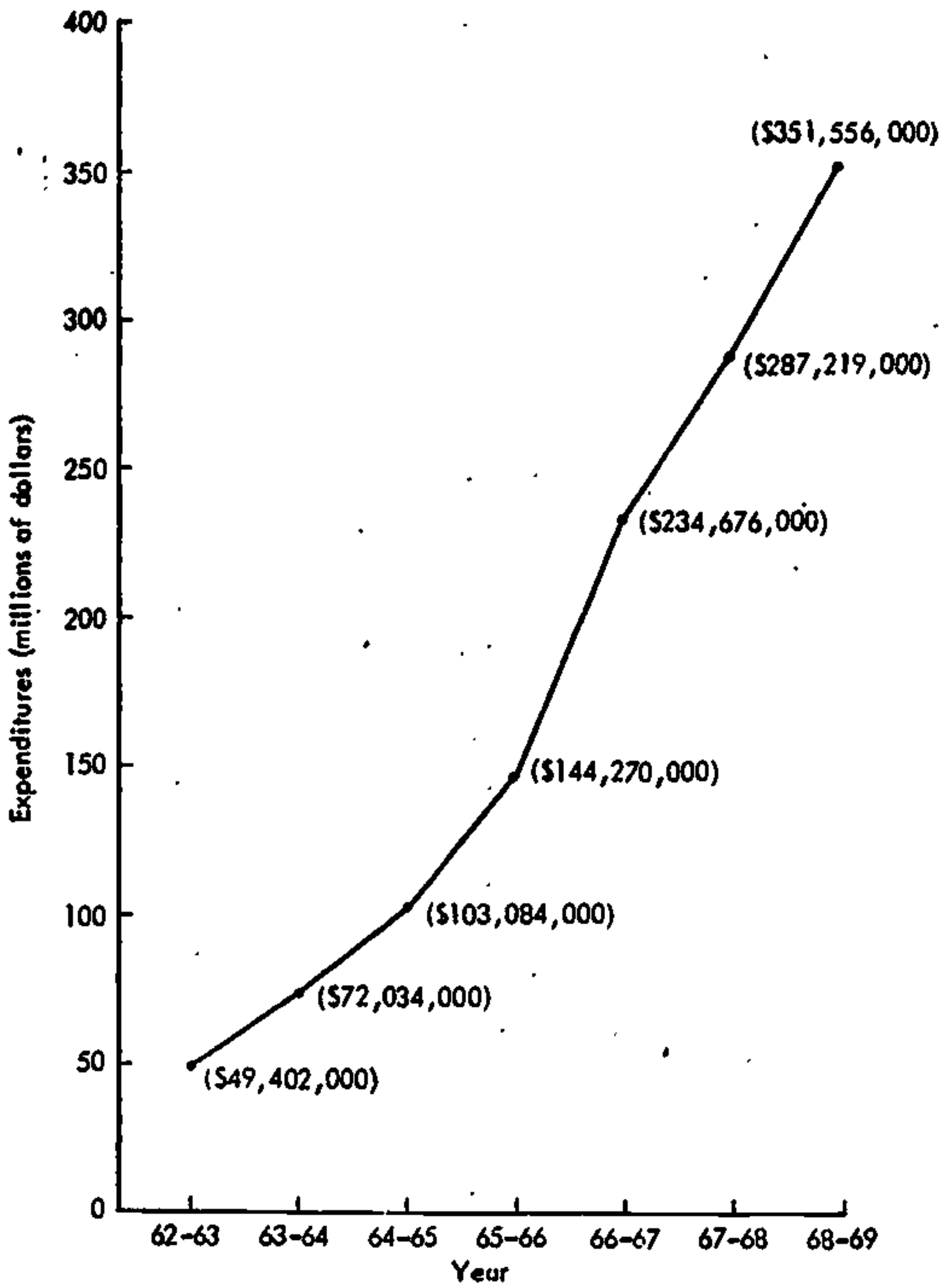


Figure 8. Expenditures on Computer Activities by Institutions of Higher Education [Ref. 5]

Table 1

COMPUTER USE BY INSTITUTIONS OF HIGHER EDUCATION (1966-67)
(+ = no schools in category)
[Ref. 5]

Degree Level and Enrollment	Public Institutions			Private Institutions		
	Total	Using Computers		Total	Using Computers	
		Number	Percent		Number	Percent
Associate						
Below 500	100	10	10	187	5	3
500-2,499	256	120	47	87	15	17
2,500-9,999	116	80	69	4	2	50
10,000-19,999	23	19	81	+	...	...
Over 20,000	+	...	...	+	...	...
Bachelor's						
Below 500	10	1	14	247	8	3
500-2,499	65	31	48	461	112	24
2,500-9,999	24	21	86	22	15	69
10,000-19,999	1	...	...	1	1	100
Over 20,000	+	...	...	+	...	...
Master's						
Below 500	4	2	50	97	8	8
500-2,499	40	17	41	156	63	40
2,500-9,999	133	116	87	58	46	80
10,000-19,999	8	8	100	2	2	100
Over 20,000	10	10	100	+	...	...
Doctorate						
Below 500	32	6	18	38	4	11
500-2,499	53	38	72	48	29	61
2,500-9,999	49	47	96	45	43	94
10,000-19,999	53	52	98	17	17	100
Over 20,000	24	24	100	6	6	100
All	1,001	602	60	1,476	376	26

are taken into account: Of the total public enrollment, 17 percent are without computers, as compared to 44 percent of the private. About half of the students without access to the computer fall in the following three categories:

Control	Degree	Enrollment	Percent Without Access
Private	Bachelor's	500-2,499	25.1
Public	Associate	Below 500	12.5
Public	Associate	500-2,499	12.8

2.2.3.2 PSAC Report

In 1967, the President's Science Advisory Committee (PSAC) panel on computers in higher education* declared that it is in the national interest to have adequate computing facilities in all institutions of higher education by 1971-72.[27] The panel estimated that some 35 percent of the students enrolled in institutions of higher education would require substantial use of computers and would need some 130 hours of console time per student for the four-year programs, that 40 percent of the students would use computers on a limited basis and would require 46 hours of console time per student, and that some 25 percent of the students would be the casual users of the computer requiring some 18 hours of console time per student. The average student, then, would require about 17.25 hours per year of console time. Assuming that one-half minute of actual computer time is necessary (with highly efficient operation) for one-half hour console use, the actual computer time needed for every student would be about 18 minutes every year. Today, for a typical IBM 360/50 computer system operation, the Computer Processing Unit time costs some $4.5 per minute. This means that the cost of providing "adequate" computation services to students enrolled in institutions for higher education would be about $78 per student per year.

In 1967, the PSAC panel[27] estimated that 20 hours of console time would cost in the neighborhood of $60 if highly efficient regional computer systems with extensive time-sharing were to be used. However, until today very few such centers have come into existence and any evaluation of what is available to students today would have to be

*PSAC panel on Computers in Higher Education study has been described by many as the most far-sighted effort that has been made to date to translate the computer's meaning for our society into educational policy. The panel was chaired by Dr. John R. Pierce of Bell Telephone Laboratories and had twelve members including two from Washington University, George Hazzard and George E. Pake.

based on a "typical" Campus Computing Facility charge. We believe $78 per student to be a good estimate for 18 minutes of CPU time. In the fall of 1969, the total student enrollment in institutions of higher education was 7.92 million. If all of these students were to be provided adequate computer services, the cost for providing such a service would be around $618 million. However, even the most optimistic estimates regarding higher education computer expenditures in 1969-70 are in the neighborhood of $430 million. One must remember that the computer expenditure also includes computer usage for administrative purposes.

In 1966-67, instructional applications accounted for 30 percent of the total expenditure.[23,26] Assuming that the same ratio still held good during 1969-70, we find that only $129 million is attributable to instructional applications. This means that on an average, each of the 7.92 million students had only 3.62 minutes of CPU time available for instructional use. Moreover, as it was discussed earlier, whatsoever computer access that is available today is inequally distributed favoring students at larger schools and those granting higher degrees. According to Hrones,[51] certain institutions, which have led in developing services for higher education, are spending in the range of $600-800 per student per year in computing activities, and in numerous large institutions an annual expenditure of $100-200 per student is not uncommon. This means that a large number of students who are enrolled in smaller and particularly private institutions for comparable degrees, are receiving computer time much below the current average of some 4 minutes of CPU time for instructional purposes, and will graduate lacking certain skills that students enrolled in larger and/or public institutions would have acquired.

Comstock's[23] projections also show that in only three classes of institutions will the students have reached the expenditure level advocated by the PSAC panel by 1971. These are all doctoral institutions--public institutions granting doctorates with enrollments in the bracket of 500-2,499 and private institutions granting doctorates with enrollments in the range of 500-2,499 and 2,500-9,999. In brief, we are far short of the goals that were established by the panel on computers in higher education of the President's Science Advisory Committee (PSAC) and some means have to be found not only to meet the prescribed goals but also to provide students in any college or university an equal opportunity for computer access.

An exact division of computer activity into various applications (research, administration, instruction and other) is difficult because instructional accounts do not differentiate clearly or accurately. As Comstock[23] has observed, administration and sponsored research cause the least confusion; unsponsored research and instruction the most, for they become easily confused primarily due to the accounting procedures. In spite of these difficulties, Hamblen's[26] comprehensive survey does attempt to provide an estimate of the various computer applications by their proportion of the total expenditure. For the academic year 1966-67, the shares were:

Research - 40 percent, about $95 million.
Instruction - 30 percent, about $69 million.
Administration - 28 percent, about $65 million.
Other* - 2 percent, about $5.8 million.

In addition to providing estimates of how computer activity is divided and the expenditures involved, these data make it clear that simple aggregate expenditures for computing in higher education by no means accurately reflect instructional activity. Seventy percent of all computer activity is for purposes other than instruction.** Campus computer activity and instructional computer use are simply two quite different stories.

Hamblen's data[26,28] shows, as one could expect, that instructional use is much heavier below the doctoral level for both public and private institutions and that research expenditures are concentrated in the doctoral institutions. What is more interesting, and perhaps less expected, is that instructional expenditures do not show a similar degree of concentration. The doctoral institutions account for only 50 percent of the expenditures for instructional computer use among public schools, and only 63 percent among private schools. Among the public institutions, the principal other sector of high activity is of course the two-year colleges (31%); among the private institutions, those granting bachelor's (13%) and the master's (22%).

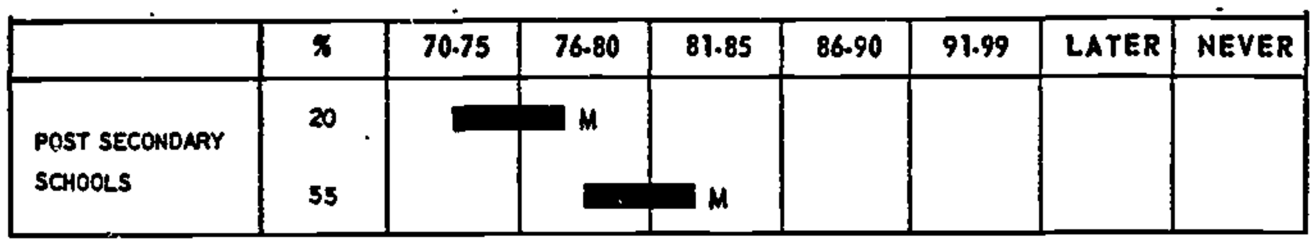
2.2.3.3 Development of Computer Services

Turning towards some of the qualitative changes that have taken place in higher education computation activities since their inception some two decades ago, one finds that the development could be best described by dividing it into four distinct phases.[29,30] Phase I of the development began in the early 1950's with the entry of commercial machines and the widening of computer applications to disciplines other than mathematics, statistics, and engineering. Previous to this phase, universities were primarily involved in the design and building of one-of-a-kind machines primarily for the specialized uses of the various government agencies and campus computer applications were primarily oriented towards computer specialists themselves. During Phase I, most academicians gave up the

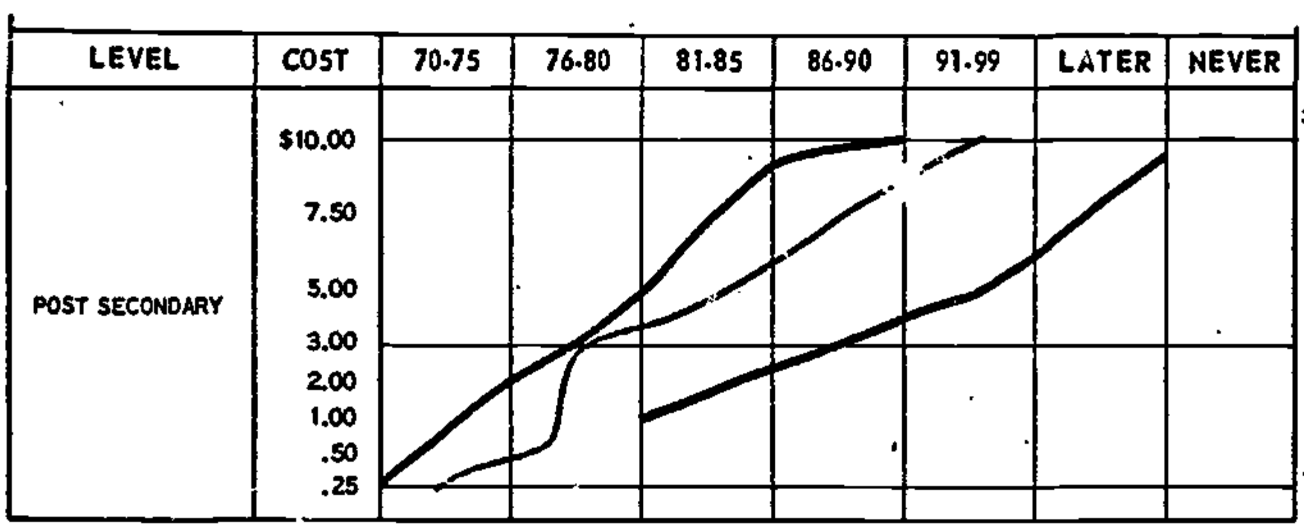
---

*Other use includes noneducational activities and use by other educational institutions.

**In view of the decreasing cost of the computer hardware and increasing computer cost/performance, it is expected that in the near-term future, instruction with computer will show increasingly competitive cost-effectiveness relative to alternative modes of instruction.[3] Decreasing computer costs will promote increasing computer usage in the existing instructional applications and will also open new avenues for computer utilization. In the Bell-Canada Delphi study[17], American panelists predicted a 20 percent utilization of Computer Assisted Instruction by 1978 and some 55 percent utilization in the early 1980's at post-secondary level of education. Figure 9 shows the dependence of the adoption of CAI on the cost factor ($ per student hour) for higher education.



The Adoption of CAI



Cost Per Student Hour in Introducing CAI

Figure 9. CAI Adoption in Higher Education [Ref. 17]

idea of building their own complete computer systems and industries started assuming a leadership role in this area. The net effect was the introduction of general-purpose computers like UNIVAC I, IBM 701 and IBM 650.

Phase I gave way to Phase II in 1956 when International Business Machines (IBM) bestowed gifts of IBM 704 computers to form university (and also regional) computer centers at MIT and UCLA. It was also the year in which the National Science Foundation (NSF) began its Institutional Computing Services program of facilities grants. During the next eight years computer centers sprouted and grew at colleges and universities throughout the country--however, the growth was not evenly distributed among all classes of higher education institutions. In the early years it favored large and elite universities and colleges and particularly those interested in the research aspects. This was also the time when the second generation computer systems were introduced--computers like IBM 7044, 7094, etc.

In 1964, IBM announced its upward compatible system 360 line and thus ushered in Phase III in this revolution. Other manufacturers soon followed suit with their own models of third-generation computers. As Greenberger[29] has observed, the production of operating systems for these computers turned out to be much more costly, time-consuming, and difficult than anyone anticipated, and their efficiency was disappointing. In addition, most third-generation machines were incompatible with their second-generation predecessors in a software sense, and program libraries had to be extensively redone. Phase III, although a period of continuing growth and markedly increasing computing budgets, thus brought with it a great deal of frustration and chagrin. One of the greatest disappointments of this period was the failure of large-scale time-sharing to meet the expectations held for it at the beginning of the period. According to Greenberger[29], only at MIT, where time-sharing in the grand manner was conceived, did it prosper and expand. Time-sharing on a more limited scale, by contrast, was successfully developed at several places: Dartmouth College, the Rand Corporation, and Berkeley, among them. A significant important development during Phase III was a significant decrease in cost and increase in power of small computers, reflecting advances made in application of integrated circuitry. Many users, within the campus itself, were able to acquire substantial equipment themselves for the first time, thus reducing their dependence on (and their association with) the main computing facility.

It should be recognized that during Phases II and III, both the federal government and the computer industry made crucial contributions to the development of campus computing. NSF's Institutional computer facilities grants and the funneling of tens of millions of dollars per year into university computing through Advanced Research Project Agency (ARPA), Atomic Energy Commission (AEC), Department of Health, Education and Welfare (HEW), Office of Education (OE), National Aeronautics and Space Administration (NASA) have given campus computing its first breath of life and has remained an active (if not entirely dependable) sponsor and client. Private industry supported universities initially by outright gifts of equipment, later by a regular program of educational discounts, and also by award of unrestricted gifts, fellowships, grants and project support, specially for the development of programs and new applications. IBM's educational discount rate started out at 60% but has since dwindled to 10% (1970) due to continued antitrust pressures.

The emergence of Phase IV in the development of campus computing is credited to the year 1970. This Phase finds the university/college computer center hurting from all sides: annual increases in budgets were markedly reduced* (as in the days of general university budget tightening). The budget item for computing was often the first place university administrators looked for savings and the NSF terminated its Institutional Computing Service Program as a part of a general government move away from categorical support for institutional facilities; educational discounts were lowered further while fourth-generation computer systems have started coming out of the production line ready for use.

The tightening of general university funds, in general, and computing facility funding allocations, in particular, is forcing educational administrators to look carefully for ways in which they can increase their revenue and also increase the service supplied per dollar. Towards this end, administrators are planning for more efficient utilization of the available or future computer resources and generating additional revenue by selling surplus computing power to neighboring computer-poor institutions which do require certain limited computing power but do not have sufficient load and/or funding to justify their own facility. Many schemes for resource sharing are also coming into effect for providing a better match of computer resources and user institutions. Several resource sharing efforts are already under effect; the total number is around one hundred.[31] Among these, the manufacturers users groups, typified by SHARE with 800 universities, are prominent. NSF sponsors 22 regional networks, most of which attempt to make the resources of a computer-rich institution available to local computer-poor schools and also to sell surplus computing capacity to generate additional revenue. Several states have or are contemplating networks within a state university system. A number of joint computer centers, each owned in common by several universities, have sprouted.

University people have also gotten interested in a network of highly-developed (in terms of computer capabilities) nodes that are electrically connected and mutually supporting so that the user can browse around and get the best buy to match his requirements and resources.[32] A national network for resource sharing is operated by EDUCOM. However, a major obstacle in the development of such interconnections has been the inadequacy of the existing commercial telecommunications plant, designed primarily for the purposes of analog signals, and the high cost of communication. A large number of so-called networks are primarily operating by mail exchange of software.

No discussion on computing in higher education would be complete without mention of the Defense Department's Advanced Research Projects

*According to a February 1969 survey of National Association of College and University Business Officers, the proposed annual budget increases for computing centers for 1969-70 and 1970-71 for 37 major universities that were polled were only 10% and 8% respectively in contrast with an average increase of some 27.3% in the previous four years.

Agency (ARPA) experimental computer network that interconnects 20 autonomous, independent computer systems to permit interactive resource sharing between any pair of systems--sharing of programs, load, data and specialized facilities. Description of the historical developments as well as the structural organization and implementation is provided by Heart et al.[33] Here it suffices to say that of the 20 computer systems that are interconnected, 12 are located in universities that have been conducting research on time-sharing computer systems for ARPA and the remaining eight belong to industrial research organizations like Rand Corporation, Stanford Research Institute, Mitre Corporation, etc.

Figure 10 shows the various nodes in the ARPA system, network topology and the computers that are interconnected. Each time-sharing center is connected to a nearby Interface Message Processor (IMP), which is a dedicated store-and-forward message switching computer. The IMP's in turn are interconnected via a network of broadband (50 kilobits/second) communication lines.[33,34,35] The existing network, in addition to its usefulness for resource sharing and encouraging interpersonal communication among team members of a research project scattered over a number of widely dispersed locations, provides a valuable tool for study evaluation and the experience needed to design and implement future computer networks. The experience with the ARPA network and the supporting analytical research has been a major stimulant in the development of many inter-university computer networks such as the one currently operated by the Princeton University, Carnegie-Mellon University and IBM[36], one operated by the Stanford University in San Francisco Bay area to provide computing power to local schools[39], and the Triangle Universities Computation Center facility that provides computing services to universities and colleges throughout North Carolina.[37,38] The North Carolina facility is rather unique as it is an operational system and has been able to cut across the traditional financial and political boundaries of individual universities.

2.3 PROVISION OF COMPUTER SERVICES

2.3.1 Introduction

In the previous sections, the various needs for computers in educational institutions were discussed: administrative, instructional, research oriented, and those related to information retrieval. Frequently, the same computer service meets all these needs. In many instances, however, separate services for administration or specialized research use exist. The decision-process for the establishment of computer services can be broken into two somewhat interrelated tasks. The first task is concerned with the provision of the basic computer service and requires decisions concerning five major issues:[5](1) modes of user access, (2) sources of services, (3) equipment, (4) management and staffing, and (5) funding. The second task is related to the computer's effective utilization (as the basic service is no more than the computer itself), the software operating system that manages its efficient utilization, and translators for a number of programming languages. To turn this basic service to the ends of administration, research, or instruction requires the programs written for specific usage, which are generally called "application programs". Provision

ARPANET
MARCH 1972

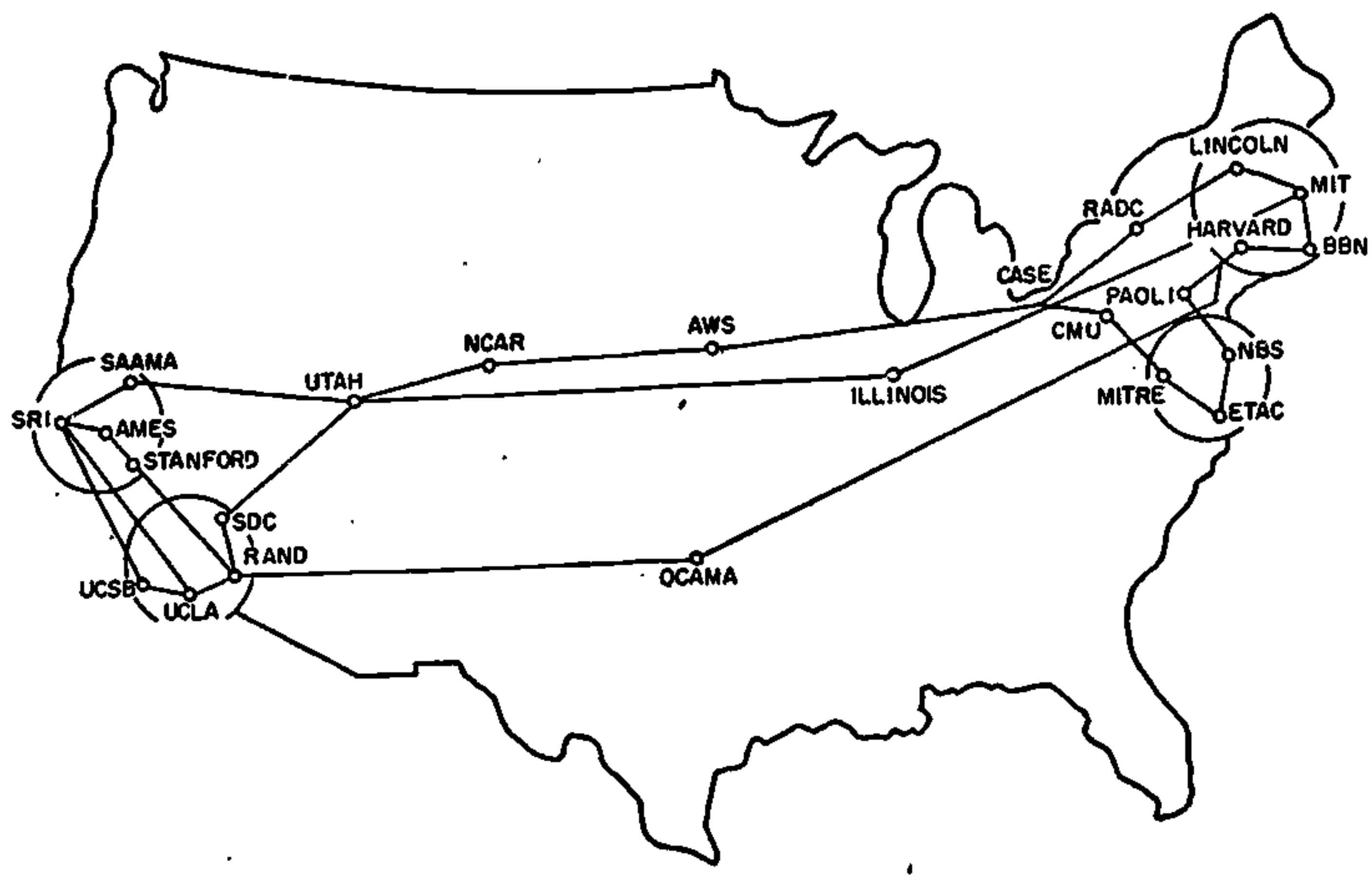


Figure 10. ARPA Computer Network Topology

of these "application programs" can take five forms: (1) Direct use - where the user writes his own programs; (2) Programmer Advice - where a programmer helps the user over difficulties in program writing; (3) Interactive - where program aids stored in the computer help the user in writing programs; (4) Programmer Assistance - where a programmer writes the application program for the user; and (5) Program Package - where the user employs an application program written by someone else.[30] In the following paragraphs, we shall be mainly concerned with the first two issues related to basic computer services and some of the options available for their provision.

2.3.2 Modes of User Access

The options for user access to the computer range from direct, immediate interaction between one user and the machine to remote and delayed interaction through a human intermediary. Table 2 classifies the computer systems by whether they are interactive or non-interactive and whether they involve simultaneous access by more than one user or exclusive use by a single user.

Non-interactive access means that the computer user and the computer do not have any two-way communication during the execution of the user's program. The computer may print various data during execution, but the user has no way to interact with the computer at the time of execution. Usually, none of the results of the program execution are seen until after completion of execution.

TABLE 2

MODES OF COMPUTER ACCESS[4]

	Non-interactive	Interactive
Simultaneous Access by more than one user	Multi-Programming Remote Batch	Time-Sharing
Access by one user	Batch Processing	Dedicated System

On the other hand, in an interactive access system, the user and program may have a great deal of communication during the execution of the program. Such systems permit the user to monitor his program during execution. In addition, the program may include points at which user enters new data. The important distinction between interactive and non-interactive systems is the two-way communication that can occur during program execution in interactive systems. The human response or input occurs at relatively slower speeds--some 10-50 bits/second depending upon the terminal that is employed. The computer response is relatively faster--100 to 10,000 bits/second.

In many computer systems, access to the computer is limited to one user at a time. The computer belongs exclusively to this one user during the execution of his program; other programs do not interrupt its execution. In a non-interactive, one-user system or Batch Processing system, the user typically submits programs to a central computing facility. These jobs are run on the computer in an order established by a computer job scheduler. The turnaround time (time between job submittal and job completion) may be minutes, hours or longer, but is ordinarily measured in hours, and sometimes in days.

A one-user system can be interactive, as a dedicated system. For instance, while a program is in execution, the computer operator can display registers and alter contents of the computer.

Simultaneity of access refers to systems in which execution of one program is interspersed with the execution of one or more other programs. The computer jumps from program to program, not performing execution of one entire program as a unit, but executing portions of many programs--either to allow interactive capability to a number of users as in time-sharing, or to allow more efficient use of different computer components, as in multi-programming. Although multiple user access to the computer may be generally called time-sharing, the term "time-sharing" has come to mean a time-shared computer with interactive remote users. The following definitions will be used throughout this memorandum:

*multiprogramming -- non-interactive, non-remote time-sharing

*time-sharing system -- remote, interactive time-sharing

*remote batch -- remote, non-interactive, non-time-sharing, or, time-sharing

In multi-programming systems, the users do not interact with their program during its execution. Programs are submitted to a central computing facility where they are run and then retrieved by the user. Swapping of execution of programs is done to maximize machine efficiency. Time-sharing systems on the other hand are interactive. The user, through the use of a teletypewriter or a CRT display with a keyboard, has the computer virtually at his fingertips and may enter programs, compile them, edit them, enter data, and receive output data. There is a central computer to which the remote users are attached via telecommunications lines and teletypewriters (see Figure 11). The user calls the computer and then begins entering his program or data on the teletypewriter/CRT unit with a keyboard. Remote batch users are linked to the computer via telecommunication links as well. In this mode the remote user requests that a job be run at some later time. The output may be returned to him via messenger or through a remote printer or card punch. User does not interact with the program during its execution in this mode of access.

The choice between batch processing and time-sharing has been the subject of much discussion since the inception of time-sharing.[44,45] For a given environment and a given set of application parameters, one can provide a set of powerful arguments which build a strong case for or against the time-shared system, even if it is not possible to prove the general

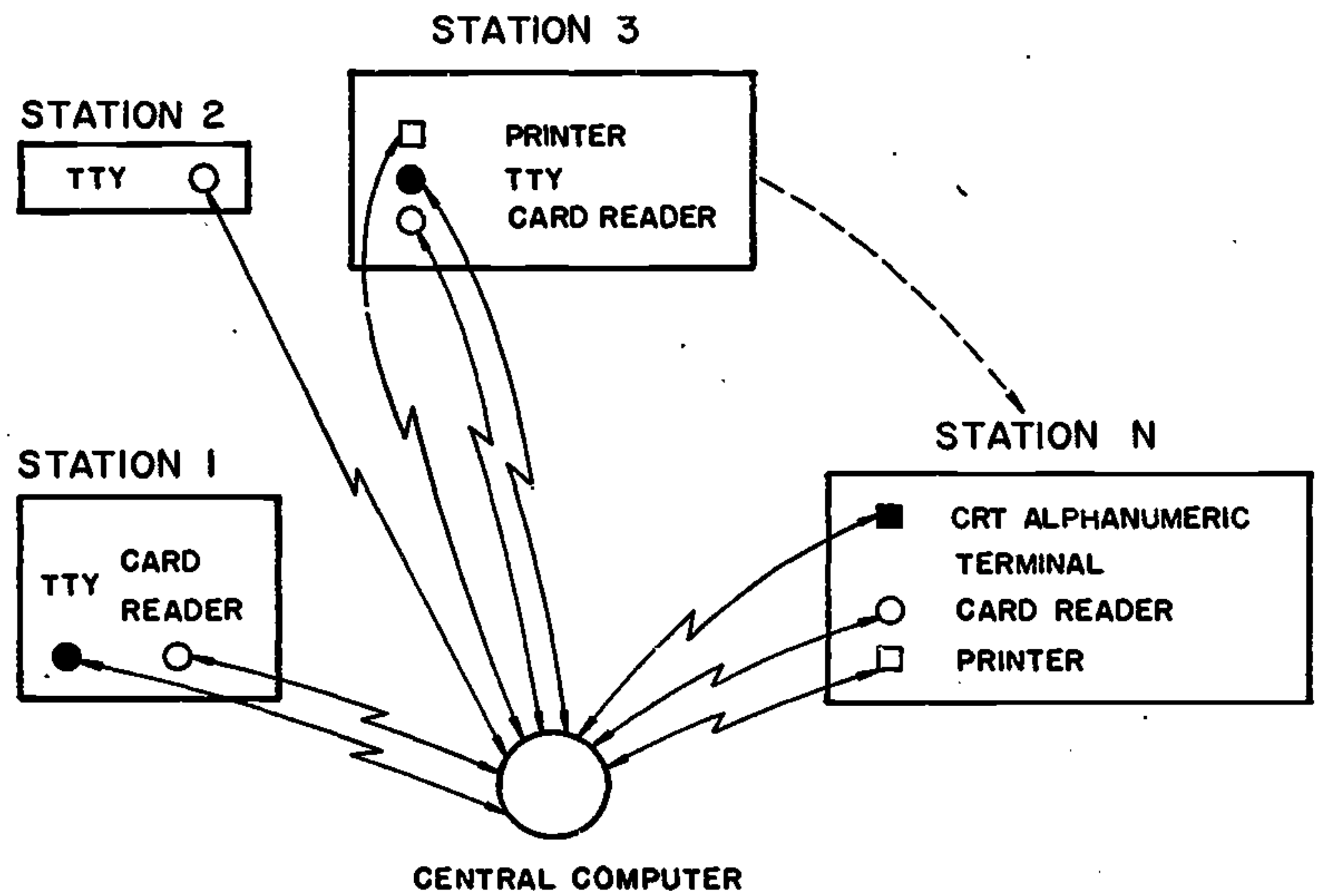
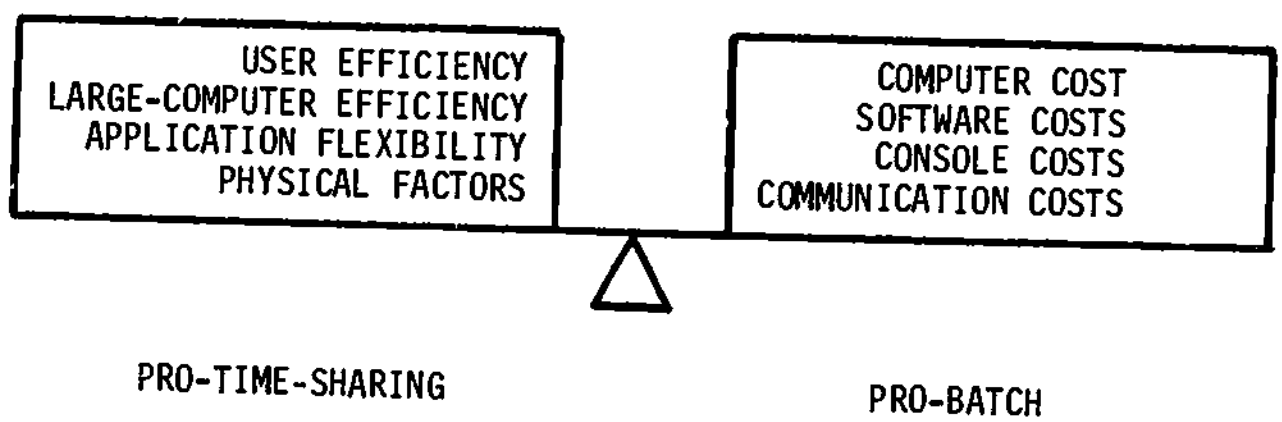


FIGURE 11 CENTRALIZED COMPUTING NETWORK

case pro or con. In many applications, the user objective and requirements of the system are such that the time-shared character of the system is, for all practical purposes, mandatory--applications that require ready response from the machine and where user interaction with the machine is needed. However, there are many cases in which a choice does exist--cases where waiting time is not a factor or where the waiting or turnaround time experienced with a batch processing systems is permissible. Figure 12 shows the factors that favor time-sharing vs. the factors that favor batch processing. Inevitably, the choice between time-sharing and batch processing reduces to consideration specific factors related to user needs; the weightage of each factor shown in Figure 12 will determine how the scales are tipped.



TIME-SHARING vs. BATCH PROCESSING[44]

Figure 12

The factor of "user efficiency" is most frequently cited as an argument in favor of putting the user directly on-line. There are few documented studies, but what evidence there is tends to support the argument. One practitioner claimed increases in efficiency of 3:1 to 5:1. W. B. Moore of Rome Air Development Center and Erwin Book of System Development Corporation have independently reported increases in programmer efficiency on the order of 7:1 in coding and debugging program modules.[44] A thorough study conducted by Gold[45] on the comparison of the values of time-sharing and batch-processing in a problem-solving situation has indicated that there seems to be no justification for hypothesizing that usage of a time-sharing computer for problem solving will cost more (or less) than such usage on more traditional computer systems. It does appear, however, that faster feedback of output will allow a reduction in the amount of man-time required to attain a given level of performance while increasing the amount of computer resources used. Higher level of performance might be achieved with the same or less man-time as required under batch. A major advantage of time-shared services due to faster feedbacks, greater ease of access, higher rates of interaction, as well as higher qualities of feedback is a more favorable reception by the users than computer systems without these features.[52]

One of the major problems that must be solved in any computer system with multiple access to a set of files (a characteristic of all time-sharing systems) is that of file security--restricting access to a particular data base to a specified set of users. For certain educational applications, particularly those related to personnel management and certain kinds of researches, controlled access to the computer may be a basic requirement if time-shared services are to be used as opposed to a dedicated computer. The security systems in use today take two general forms:[4] systems which restrict file access to a particular set of terminal devices, which have identifying codes built into the hardware; and systems which restrict file access to a particular set of persons, independent of the terminal device, who may unlock the file through the use of a particular code word, entered into the input device. The first is comparable to a physical lock opened with a key; the second is comparable to a physical lock opened with a combination. For physical files, neither of these devices is fully satisfactory; but they are the best means devised for security. The procedures for file security in computers, at the present stage of development, seem no worse and no better (except that access cannot be obtained purely through physical force, as in dynamiting a safe) than the methods for physical file security. They are not perfect, as no security system is, and they carry no unique hazards not shared by physical file systems and should not act as a deterrent to the use of centralized time-shared computing.

2.3.3 Sources of Service

The choices here hinge on the choice between on-campus and off-campus services and between cooperative or commercial ventures.[5] The major options that are available to the decision makers can be summarized as: (1) Centralized on-campus facility; (2) Distributed on-campus facility; (3) An off-campus commercial facility; and (4) An off-campus cooperative venture with neighboring colleges and universities. Here one should clearly understand that the choice of the source is not independent of the choice of the mode of access and vice versa. Table 3 shows the feasible combinations of the mode and source.

Centralized on-campus computer facilities have often been the unquestioned choice of educational institutions, particularly those belonging to higher education, because such facilities have the appearance of a scientific or instructional tool. Depending on size, budget, and user needs, such a center can provide user access in any of the five modes described in Table 2. A college with few users, each with small problems, may very well select a single task system. When such a system becomes congested, the college may move to a batch processing system. Remote batch is not inexpensive; it will be considered in institutions large enough (geographically) to make physical access a serious problem. An institution with many users and a sufficient budget will certainly consider an on-campus, time-sharing system as an attractive alternative. The advantages of centralization arise from economies in computer cost resulting from fuller utilization of large scale, lower cost-per-unit of computation machines, and from sharing of scarce staff, programs, and facilities. The disadvantages derive from a central facility's relative unresponsiveness to local time-urgent demands and from the problem of providing and balancing the wide range of services demanded on an active campus.

TABLE 3

MATRIX OF COMPUTER ACCESS AND SOURCE OPTIONS[4,40]

Source of Service	Mode of Access				
	Dedicated	Batch Processing	Remote Batch Processing	Multi-Programming	Time-Sharing
Centralized On-Campus Facility	X	X	X	X	X
Distributed Computers On-Campus	X	X		X	
Commercial Service Off-Campus		X	X		X
Shared Cooperative Facility Off-Campus		X	X		X

A totally different approach to on-campus facilities is possible where each user group is left to provide for its own requirements, usually with the acquisition of small computers. There are often good reasons for allowing some users to have their own machines dedicated to their own problems: computer science students must sometimes undertake experiments that would be disruptive of normal service; administrative users may feel that their privacy, load and job-mix requirements are incompatible with a multiple-user service; research users may have experimental control requirements (very fast response time, reliability, etc.) that can not be met by any centralized facility without unusual inconvenience and expense. Distributed computers, like those in a centralized facility, can provide access in several modes. Because they are used by fewer people, they are normally smaller and thus more likely to be used in the dedicated or batch mode. Disadvantages generally attached with a distributed facility are higher cost per unit of computation than for large machines and the fact that sharing of programs and services has been harder.

Service Bureaus and the newly developing computer utilities offer another source for procuring necessary computing power. Service Bureaus purchase or lease computer equipment and hire staffs of programmers, analysts and operators. They offer computer services to others, providing an alternative or supplementary source of computation for the users who prefer not to obtain equivalent equipment directly. Though no new data is available on the current population of these Service Bureaus, in 1966 there were over 800 of them.[41] Time-shared vendors or "computer utilities" could be differentiated from the service bureaus on the basis of the use of remote input/output stations. Computer utilities provide both time-shared computing as well as remote batch processing, whereas Service Bureau services are mainly limited to Batch Processing and the user is required to physically transport his program to the Service Bureau facility.

A large number of "computer utilities" have come into existence and their number is increasing. A recent survey[42,43] provides detailed information regarding various time-sharing services--area covered, facilities CPU, response time, charges, file structure, software, applications packages, and multi-user, on-line data bases, if any. These have very attractive characteristics for institutions making their first investment in computing, since the set-up costs are small, the convenience is great, and the price is very largely a function of how much of the service is used. The institution has the choice of browsing around and buying the suitable service from a large number of strongly competitive time-sharing vendors or utilities. If an institution decides that it is preferable not to provide any computer on campus, but to arrange for the service through some utility or service bureau, the reasons are likely to be one or more of these: (1) It is less expensive (capital and/or operating expense); (2) It requires less long term commitment; (3) It requires less management or administrative supervision; and (4) It provides higher quality and wider variety of services than those obtainable through a smaller computer system on-campus.[40] Some institutions will select this alternative when their need is for very little computing (thus making other alternatives relatively more expensive), when the need is imminent (and there is no time to arrange for other alternatives), or when it is expected that the requirements will drop off very soon or the requirement profile has a large variation with respect to time.

Still another possibility is the sharing of computing power with other colleges and universities--either by establishing a joint on-campus facility on a time-shared and/or remote batch basis <u>or</u> by buying surplus computing power from a neighboring computer-rich institution at non-peak hours. Sharing of computing power via regional networks (whether remote batch, time-shared or intelligent terminal) has special significance for smaller (with enrollments less than 2500) colleges with no doctoral programs--institutions that number about 2,500 today. As Weeg[87] has pointed out, probably underlying the computing need of these institutions is the need for limited raw batch processing capability without any excessive capital investments. A deliberately designed non-profit cooperative effort could further reduce the computing charges than those available through service bureaus or commercial time-sharing service. Best known of such cooperative efforts in the United States is the "Triangle Universities Computation Center", a computer facility serving North Carolina State, Duke, and the University of North Carolina, as well as a number of smaller colleges in the state.[37,38] Its experience seems to indicate that cooperative facilities may be an important alternative to the situation in which each institution provides its own on-campus facility.

The question of the economies of scale and specialization on computing has been a subject of serious discussion and much writing.[30,46,47,48,49] As early as in 1940's, Grosch asserted that computer equipment average cost decreases substantially as size increases and that effectiveness is proportional to the square of the cost, i.e.

$$C = K\sqrt{E} \qquad \text{or} \qquad E = [1/K^2]\, C^2$$

where, C = the cost of the computer system, E = the effectiveness (performance, speed, throughput) of the system, and

K = some constant.

Recent studies by Knight[30,47] and Solomon[48] have also verified the economies of scale that are involved in large computing systems; however, it has been found that scientific computing, that relies heavily on the capabilities of the Central Processing Unit, approaches Grosch's law more closely than commercial computing.

One could write Grosch's law as

$$\frac{C}{E} = K\,C^{1 + (1/b)}$$

where, $b = -0.5$, and $C/E = KC^{-1}$.

Solomon[48] used four instruction mixes to measure the processor performance of five compatible models of IBM 360 series (30,40,50,65, and 75)--each instruction had a different mix of fixed and floating point 32-bit operations, logical operations, branching, and status switching. Following are the performances as measured by Solomon.

Instruction Mix	b	Equation
Matrix Multiplication	-0.4935	$C/E = KC^{-1.026}$
Floating Square Root	-0.4783	$C/E = KC^{-1.091}$
Arbuckle's Scientific Mix	-0.6319	$C/E = KC^{-0.582}$
Field Scan	-0.6817	$C/E = KC^{-0.466}$

The calculations indicate that instructions (matrix multiplication and floating square root) that heavily involve fixed- and floating-point operations, were closer to Grosch's law and exhibited greater economy of scale than instructions (Arbuckle's Scientific Mix and Field Scan) that are weighted heavily towards load/store, indexing, branching and logical operations. Cox[49] has verified this in a separate paper where he computed cost per execution for two kernels, one involving a larger amount of floating point computations and less branching operations than the other, for a number of machines--from PDP-10 to CDC 6600. He also verified the large economies that are possible due to specialization--running a program on a machine especially assembled for the problem.

In view of the technological advances that have taken place in the last decade in processor and memory technology due to the advent of the Integrated Circuits and Large Scale Integration (LSI), some observers have ventured to suggest that the economies of scale in computing are decreasing over time. However, Knight's comprehensive studies[30,47] suggest, that if anything, economies of scale have increased over time.

ERIC

Though there is no doubt that large centralized computer facilities that are shared by many educational institutions will continue to develop, both in numbers and capabilities, and will be a major source of computing power for many computer-poor institutions, the development of small, cheap minicomputers and their application to the education should not be ignored. Minicomputers are readily distinguishable from larger computer systems by their shorter word length, smaller size, limited processing capabilities, and significantly lower prices. A large number of minicomputers are available with varying capabilities, and today, one can buy an 8- to 24-bit word length minicomputer for $4,000 to $20,000.[50] Minicomputers could be particularly useful for real-time control of experiments and computation situations where the application is repetitive and the computer and software can be dedicated to a few tasks. Minicomputers could also be useful in the teaching of computer programming, certain kinds of Computer Assisted Instruction that involve little use of floating-point computations and problem solving situations that are not very taxing on the CPU--applications that are more inclined towards indexing, branching and logical operations. As Levien[1] has pointed out, the use of minicomputers for instruction could promote the developments of instructional packages in cassette form that could be sold or rented like books or records. To some extent, this mode of providing "limited" computational facilities directly competes with the development of large, centralized computing centers that provide time-sharing and/or remote batch processing. However, one should not be deceived by the low-cost of minicomputers. They require certain operational (management and programming) expenses that may not be insubstantial and which are shared by a large number of users in case of a large multi-access facilities. According to evidence presented elsewhere[86], it seems that significant economies exist even in the centralization of computer personnel--planning, programming, systems analysis and operations. A survey of some 2,000 company computing facilities shows that personnel cost per dollar of computational equipment rental decreases as the size of the installation increases. The final choice at the institutional or departmental level would depend upon the amount and nature of computing to be performed, and special requirements such as privacy, reliability and responsiveness.

3. COMPUTER COMMUNICATIONS

3.1 INTRODUCTION

The previous two sections of this memorandum identified and discussed the prospects for those educational computing systems that involve telecommunications as an integral part of the system--systems which could be characterized as centralized or distributed computing networks depending upon their design and that provide their users access to a facility or facilities of a capability and cost beyond those available to them independently. In centralized computing networks (Figure 11), actual computing and maintenance for all users, whether simultaneous or one at a time, are carried out at a centralized location although access to the computer and to data banks is available from remote locations in time-sharing and/or remote-batch mode. In decentralized or distributed computer networks[54], the data processing activity is carried out by several installations (Figure 13). An essential difference between the two forms of information network is the existence of two forms of communications traffic in the distributed configuration. As in the centralized configuration, there are communications between remote terminals and an individual computer installation closeby. However, there are in addition, the communications between the nodes or computer installations of the network. A distributed network offers not only the benefits of economies of scale that are also available through centralized networks, but also the economies and advantages of specialization--specialized software, hardware, and data bases.

Both types of computing networks can be implemented either on an intra- or inter-institutional basis. For example, a large institution could have its own centralized facility offering both time-sharing and remote batch services at various locations within its campus or various campuses like the Regional Computing Facility in the State University of New York[55], or several institutions could establish a joint facility like "Triangle Universities Computation Center" in North Carolina.[38] Similarly, a large and computer-rich institution like MIT may very well implement a distributed computer network within the institute itself by interconnecting its various computers located at different geographical locations within the institute.[53] In the case of the ARPA network[35] and the Princeton-Carnegie Mellon-IBM network[36], computing facilities belonging to a number of educational and/or research institutions could be interconnected to permit resource sharing.

Distributed networks hold special promises for load sharing and specialized applications, particularly those related to research. However, the computation task must be sufficiently long or urgent so that the payoff in reduced charges for computation (due to the use of a specialized facility) or the gains obtained from a quicker processing balance the extra communication expense involved in transmitting the data pertaining to the job from the user's regular computer facility to another distant facility and receiving back the results. A major problem in the implementation of distributed networks today is that the computers in use in educational institutions differ from one another in type, size, speed, word length, operating systems, etc. in a large number of cases, and any interconnection of these heterogeneous modes requires an additional expense in terms of small "interface" computers for adequate compatibility conversions.

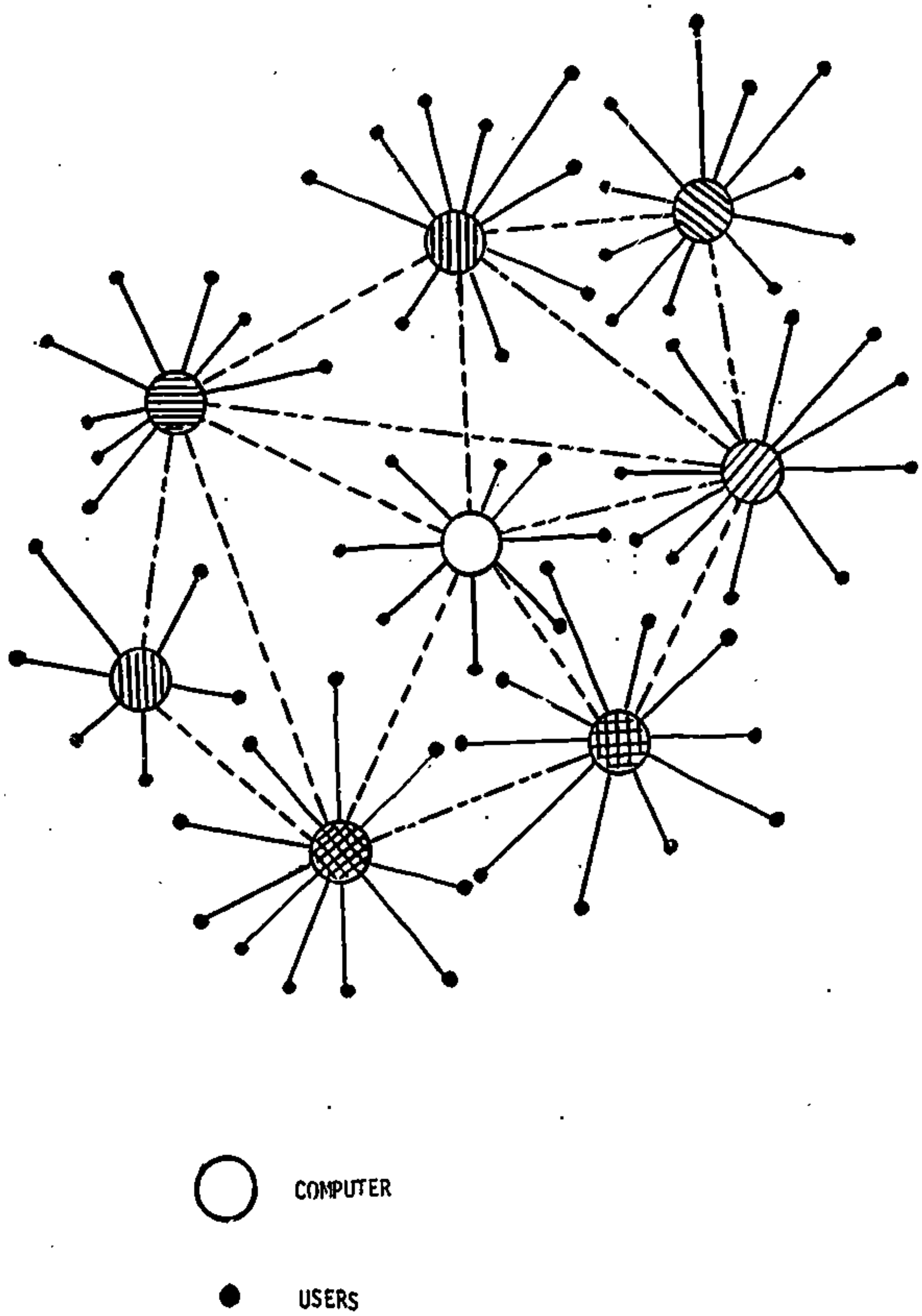


Figure 13. Decentralized or Distributed Computing Network

It seems likely that between centralized and distributed network services, it will be the centralized networks whose development will dominate the early years of network development. Both specialized and general purpose facilities would play an important role in extending the computer services and various applications to small colleges, elementary and secondary schools which lack adequate financial resources to own and operate their own facilities. Specialized educational centralized computer networks will be oriented towards storage and retrieval of specialized data--data relating to elementary particles, nuclear physics and engineering, Thermodynamics, Transport Properties, Chemical Kinetics, solid state, and atomic and molecular properties, life sciences and medicine, etc.--many of which are being maintained at several dispersed locations by various government and non-government agencies.[63] In addition, special centralized networks for educational administrative applications, personnel management and educational planning also have good prospects for development.

The pressure behind the development of these networks would primarily be economic. The dedicated educational computer networks would either be a deliberately designed non-profit cooperative effort among schools, school districts, colleges and universities in a particular region, or, would be the extension of a computer-rich institution's computer facility--an institution that wants to generate additional revenues to support its computation activities at a time when NSF institutional computer facilities program has been phased out, educational discounts for computer hardware are gradually fading away, and the budget for the computing facility is consuming an appreciable and increasing portion of the institutional regular budget that itself is facing severe hardships. Perhaps in the early years of network development, several network options will be available for the users in each geographical region. However, in view of the current telecommunication plant's inadequacy for data-transmission and the incompatibility among the various computer systems manufactured by different companies, it seems unlikely that for sometime users, with a particular remote terminal designed for operation with a particular computer system, would be able to access the network of their desire on a "switched" or "dial-up" basis. Most of the user-computer interconnection would be through private, leased, and, in many instances, through specially conditioned lines.

After the centralized networks have been in operation for sometime and certain education of the user community has taken place, alternate, cheaper and adequate data-transmission facilities will have been developed, and some standardization among various computer systems has been achieved so that computer-to-computer interface cost is reduced, it seems likely that user demand for occasional access to not-so-frequently used distant data bases and specialized services will pressure the individual top-heavy networks towards their interconnection. Thus, distributed networks would basically evolve from the development of centralized networks--first on a regional basis and later, perhaps, resulting into the interconnection of the regional distributed networks themselves on a national basis. Figure 14 presents the evolution of the distributed networks from the centralized networks in due course of time.

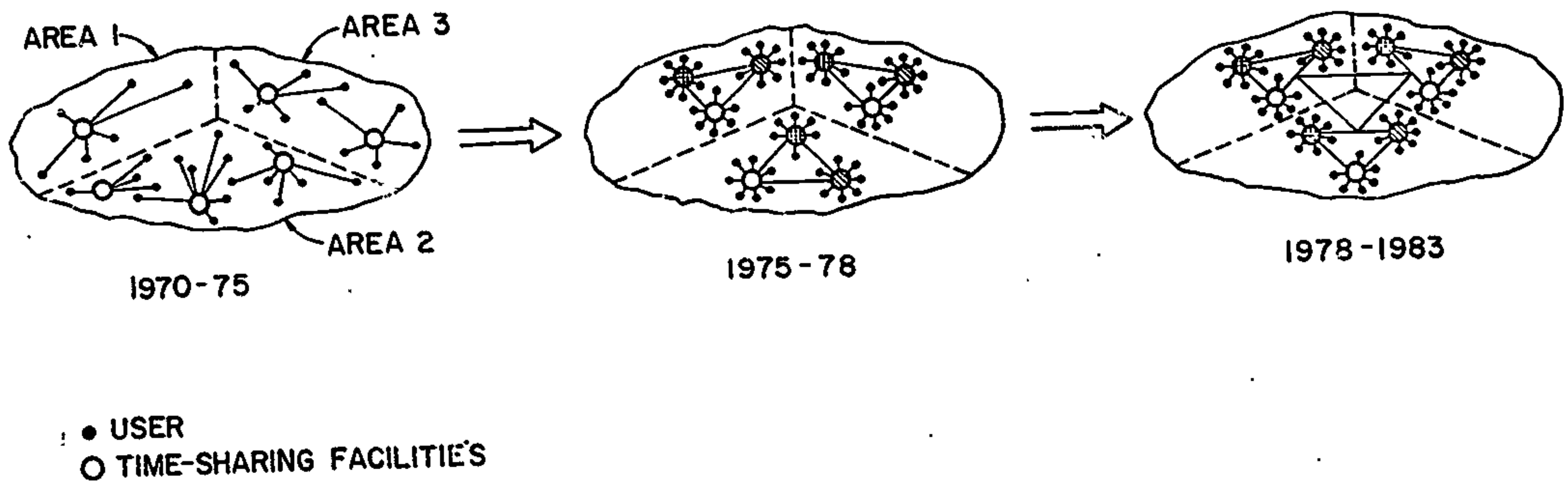


FIGURE 14 EVOLUTION OF DISTRIBUTED NETWORKS

Digital computers requiring communications with remote terminals exhibit a set of communications needs which, in some respects, are different from those of both voice traffic and other record communications. An understanding of the requirements and nature of the communications between the computer and the terminals is necessary before one can explore the possible applications for communications satellites for providing the necessary communications.

Multi-access computer communications can be divided into two classes: (1) The first type is typified by the communications involved in the time-shared computer use where a large number of remotely located users could use the computer simultaneously in an interactive fashion through special terminals; (2) The second class of communications is typified by that involved in remote batch-processing where the computer could either be used in multi-programmed or dedicated fashion. In the first type of communications, the communicators are the man and the machine and the (human) interaction takes place at relatively slower speeds. Channel requirements are asymmetric in the sense that the computer-to-remote terminal link is usually a high speed link whereas the terminal-to-computer link is low speed as the communications is limited by human response times. In the second type, the communication is between machines and it takes place at relatively higher speeds in both directions. The next sub-section will be primarily concerned with those aspects of multi-access computer communications that are important from the viewpoint of time-sharing. In addition to studying the nature and requirements for such communications, issues related to the existing common carrier plant--its inadequacy, high-cost, etc.--will be discussed. Subsequent sub-sections will focus upon machine-to-machine communication (remote batch-processing and inter-computer communication) and the examination of satellite communication for multi-access and inter-computer communication.

3.2 MULTI-ACCESS COMPUTER COMMUNICATIONS

3.2.1 Introduction

A number of studies[56,57,58,59,66] by the providers and the manufacturers of multi-access computer systems have characterized both the computer systems and their users. The principal interest of these studies, however, has been computer and/or user performance rather than the data communications that is involved. A literature search has uncovered only three studies that deal comprehensively with the communications aspects of operational systems--those by Jackson and Stubbs[60], Sykes[61], and Abramson[62]. These studies, particularly the one by Jackson and Stubbs[60], shall form the primary source for the discussion that follows in this sub-section.

The quantitative characterization of the communications process in multi-access situations is intricate. Multi-access computing is still very much in its infancy, and in the absence of a unified, well-tested body of technical knowledge applicable to the problem of multi-access computing, system designers have been led to heuristic solutions to system organization. A detailed characterization also becomes difficult in view of the fact that the operating systems are changing so rapidly and the new equipment being introduced at such a high rate that a detailed characterization will probably be outdated before it is completed. Last, but not least, are the problems created by the diverse applications of time-sharing with each application having very much its own set of response-time requirements, holding-time, remote-terminals, etc. The nature of data required for such characterization also adds to its intricacy. Unlike voice traffic, which can be characterized by measures of holding-time, arrival rates and other parameters independent of call's content, the characterization of calls to a computer requires some information about a call's content, e.g., timing information interrelating the transmission of data characters is essential for the design of any scheme for near-optimal or optimal utilization of the communications channel. Collection of such microscopic data requires new data gathering procedures and equipment, data analyses procedures capable of handling very large quantities of data, not to mention the legal and ethical requirements related to communications and computing privacy which must be satisfied.[60]

Multi-access computer systems can be characterized by the following seven system characteristics: (1) Computer type--manufacturer and model number; (2) Input-Output Device and its Speed (bits/second or characters/second); (3) Average Number of Simultaneous Users or busy ports (what may be called the loading); (4) User Community--whether intra-institutional or inter-institutional (or utility); (5) User's applications--information retrieval or computing; (6) Type of error control used in the system; and (7) The typical holding time, i.e., the time duration between the connect and disconnect of the user's call. As this memorandum is concerned with the communications aspects of multi-access computing, only the options and the current trends in Input/Output (I/O) devices, error control techniques and information coding will be explored briefly (see Appendix A) before moving on to the data-stream model of Jackson and Stubbs[60] for computer-remote terminal communications.

3.2.2 Conversational Terminals

Conversational terminals, which allow an individual to interact with a computer, fall into two categories, teletypewriters (TTY's) and visual displays (alphanumeric and graphic), though the distinction between them is diminishing and compromise approaches are developing.

Teletypewriters consist of a keyboard and a serial printer. The keyboard is like a typewriter keyboard and the printer produces hard copy (alphanumeric characters on paper) by impact. Table 4 contains a summary of the principal operating characteristics of the major types of low-speed teletypewriters currently available.[65] The transmission speeds range from 45 to 1,200 bits per second (9-50 characters/second) and the prices are between $500-$12,000 per unit. TTY's normally contain no memory beyond a one or two character buffer (and possibly a paper tape device) and very little control logic. Transmission is done on a character by character basis in an asynchronous mode. TTY's offer the advantages of low cost ($500 for one low-cost unit as compared to $5000 for a low-cost CRT based interactive display), low communications cost due to low transmission speeds, a hard-copy printout, easier operation and portability.

Table 4

KEYBOARD/PRINTER TERMINALS (TELETYPEWRITERS) [65]

Manufacturer	Model	Keyboard	Printing Speed (cps)	PPT Reader Speed (cps)	PPT Punch Speed (cps)	Codes	Transmission Speed (bps)	Circuit	Error Detection	Error Correction	Purchase Price Range ($)	Comments
Communitype	100SR	IBM Selectric	15	— (incremental magnetic tape)	—	BCD	1,200 100 (cps)	Voice	Character parity	Automatic retransmission	11,600	Also has punched cards, magnetic tape, output
Datel	30 Series		15	—	—	Any		Voice or 15 cps	Character or block parity	None		Also has magnetic tape output
Friden	7102 CMT	46-Key 91 Characters	12.5	12.5	12.5	ASCII	13?	Narrow or voice half-duplex	Character parity optional	None	3,200	
Friden	7100 CMT	91 Characters	12.2			7-level	150		Character parity			135 character per line
IBM	2740/2741	41-Key	14.8	—	—	6.8-level BCD	134.5	Narrow or voice half-duplex	Character per message parity		3,200	2741 for interrupt facility on System 360; 2740 is polled 2740-II has 120 character buffer
Invac	Unicom 30	IBM Selectric or Photoelectric	14.8 (15.5-RO)	35	35	Any 8-level	480 or 1,600 (30 cps)	Voice	Characters/ block parity	?	5,500	
Kleinschmidt	311/321	33, 52, or 53-Key 51 or 63 Characters	37.5	37.5 (321)	37.5 (321)	Baudot ASCII any 5,6,7, 8-level	110,150 300	Narrow or voice half- or full-duplex	Character parity	Lamp alarm	2,370-$4,000 (311) 5,750-$7,000 (321)	
Soroban	Compu-teriter Model ETC	IBM Model B Typewriter 44-Key	10			Any 6,7,8-level code	110	Narrow or voice			1,990	Also has 50 cps printer
Teletype	Model 28	32-Key 62 Characters	10	10	10	Baudot (5-level)	45,56 or 75	Narrow half- or full-duplex	None	None	2,200 (ASR) ..300 (KSR)	
Teletype	Model 32	32-Key 62 Characters	10	10	10	Baudot (5-level)	45,56 or 75	Narrow half- or full-duplex	None	None	580 (ASR) 425 (KSR)	
Teletype	Model 33/35	45-Key 80 Characters	10	10	10	ASCII (8-level)	110	Narrow half- or full-duplex	None	None	500(33)(KSR) 1400(35) (KSR)	33 is light-duty model; 35 is heavy-duty
Teletype	Model 37	61-Key 128 Characters	15	15	15	ASCII (8-level)	165	Narrow half-duplex	Character parity	None	2,100 (KSR)	Upper and lower case, extensive format control
Teletype	Inktronic	64 Characters	120	—	—	8-level	1,200	Voice half-duplex			5,500 (KSR)	Nonimpact printer (ink jet)
Siemens	Teleprinter 100		13	13	13	5-level		Internal net-works only				Reportedly over 100,000 in use in 100 countries

Visual displays (alphanumeric as well as graphic) consist of a keyboard for input, as does the TTY, but employ a TV-like display screen for output. Screen may either be conventional Cathode Ray Tube or the newly developed Plasma Panel.[67] A problem with CRT's is that due to limited image retention capability of the phosphor screen, the images must be "refreshed", generally 30 to 60 times each second. The data transfer rate required to refresh a display at this frequency is several hundred thousand bits per second. The image is usually stored by a terminal controller which is located near the CRT display. The memory associated with the CRT display-controller is usually large enough to store one "page" or full-screen of data. Plasma-panel displays have an inherent memory and hence do not need to be refreshed unless a change in image is desired. However, some local memory is required to enable the user to look back at the program steps that have rolled off the screen and to allow long indexes to be surveyed by file inquiries. Interactive full graphic terminals provide dynamic and manipulatable visual display of data, graphs, flow charts, schematics, and graphic projections in two or three dimensions as opposed to the display of alphanumeric data only in alphanumeric terminals. Graphic terminals are usually more costly than alphanumeric terminals--an average graphic terminal may cost anywhere between $75,000 to $150,000 whereas an average alphanumeric terminal costs between $4,000-$8,000 depending upon its capabilities. Graphic terminals also require transmission channels with higher speeds (4.8 kilobits/second to 5 Megabits/second) as compared with alphanumeric terminals (200 bits/second to 1 Megabits/second). Tables 5 and 6 contain a summary of the principal operating characteristics of CRT terminals available today based on an Arthur D. Little study[65] and a recent Modern Data survey.[68,69]

Full graphic terminals are finding use particularly in the areas of Computer Aided Design (CAD) and Simulation and Modelling.[68] However, the use of alphanumeric terminals predominates over the use of graphic terminals today. According to the Arthur D. Little study[65], there are some 1250 graphic CRT installations in use today and their population is estimated to grow to some 6,000-9,000 in 1974 as compared with some 90,000-100,000 alphanumeric terminals that are in use today and which are expected to grow to a population in the range of 150,000-200,000 in 1974. During this period, the average cost of an alphanumeric terminal is expected to drop to $1,000-4,000 range and that of a graphic terminal to $50,000-$100,000.[65]

Interactive display terminals could either be character-oriented or designed for block-mode operation. In character-oriented displays, each character is sent to the computer at the same time it is keyed and the transmission is asynchronous. In block-mode displays, first the characters that are keyed-in are stored and displayed and then transmitted in block or line form at the wish of the user. In block-mode operation, transmission is usually synchronous. In some of the display systems, where keys of the keyboard may mean different things depending upon the particular application software as in the case of displays used in the PLATO III CBI system, character by character transmission becomes a necessity and the characters are "echoed" back from the computer for display on the local screen--for computer interprets the meaning of each key according to the software in use. Sometimes a computer based "echo" is used to prevent the user trying to communicate with the computer when the computer is

Table 5

KEYBOARD/CRT[65]

Manufacturer	Model	Characters Per Line Lines Per Frame	Display Capacity (characters)	Transmission Speed (bps)	Circuit	Auxiliary Hard Copy	Purchase* Price Range ($)	Lease* Price Range ($)	Comments
Bunker-Ramo	200	64/12	768	600 to 2,400	Voice half-duplex	TT 33 RO	6,492	135	Model 212 used for stock quotations
Bunker-Ramo	400	32/12	384	2,400	Voice half-duplex	TT 33 RO			
Burroughs	Input/Display System	80/25	1,019	150 to 4,800	Full- or half-duplex	TT 33 RO	12,980	295	Core buffer memory;extensive editing
Computer Communications, Inc.	CC-30	40/24	960	Up to 500KC	Half-duplex up to broadband	Noninput printer available	6,845	NA	Uses ordinary TV as display core memory controller; limited graphics possible: light pen
CONRAC	201	37/24 37/16	888 592	1,200 bps	Voice half-duplex		7,500	NA	
Control Data	210/212	50/20 80/13	1,040	2,000 to 2,400	Voice half-duplex	Selectric	12,220	367	211 multistation, 212 single station
Ferranti	50/60	64/13	832						2 controllers--MD.5 ($20,888) for 4 displays, MD. 6($41,608) for 16
GE	Datanet 760	46/26	1,196	1,200, 2,000, 2,400	Voice half- or full-duplex	TT 33 RO	24,820 17,867*	620 338*	Limited line drawing, uses standard TV
Geospace	SAND	/36	1,040	26,000 cps					
Hendrix Wire and Cable	5100	80/13	1,040	2,400	Voice half-duplex	Page printer			
IBM	2260	80/12	960	1,200, 2,400	Voice half-duplex	1,053 (14.8 cps)	7,403	182	2265 is standalone version $14,150 purchase, $350 rental
IBM	1015	40/30	1,200						
Lear Siegler	610	32/20	640						Educational Terminal 5" x 8"
Philco-Ford	Visual A/N Data Terminal	80/20	1,600	2,000 to 2,400	Voice				
Raytheon	DIDS 400	40/13 (80 optional)	520 (1,040 optional)	120, 250, 300 cps	Voice half-duplex	TT 33 RO	6,000(402)	167	402 is standalone version, 401 uses common controller with up to 64 displays
RCA	70/752	54/20	1,080	1,200	Voice half-duplex	10 cps	8,326	$190	Standalone device Model 750 allows 48 displays per controller
Sanders	720	52/40 or 64/32	1,024 768(620)	110 to 2,400	Voice half- or full-duplex	TT 30 RO	6,142 (720) 5,400 (620)	233 180	Also light pen, punched paper tape options. Model 620 recently introduced as low-cost standalone version
SDS	7550/7555	86/32	2,048	15 cps (50) 180 cps (55)	Half- or full-duplex	TT 37 RO	10,000 (50) 12,500 (55)	225 265	Standalone only
SINTRA	TE4000	64/32	2,048						
SINTRA	TE500	40/13	520	1,300		TT 30 RO	5,600		
Stromberg-Carlson	SC1110	80/35	500 1,030	800 to 1.1 MHz	Voice or broadband half- or full-duplex	Off-line fully buffered			
TEC-LITE	5512	32/16	512	1.6 MHz	Half-duplex broadband				

Table 6

CHARACTERISTICS OF GRAPHIC CRT TERMINALS[68]

Manufacturer	Model	Character Capacity	Refresh Rate (Hz)	Data Entry	Transmission Rate	Transmission Mode	Input Devices	Purchase Price ($)
ADAGE	ARDS 100B	4160	Storage Tube Display	Line	50 Kilobits/sec	HDX/FDX	Light Pen Keyboard	8,700
ADAGE	AGT 150	3840	60 (Variable)	Character and Line	to 1 Mb/s	HDX/FDX	Light Pen Keyboard Function Keys	167,000
CONTROL DATA	240	12288	50 [Programmable]	Character and Line	....	FDX	Light Pen Keyboard	68,900
CONTROL DATA	250	8704	50	Character and Line	....	....	Light Pen Keyboard	137,800
CORNING	904	4608	Storage Tube	....	110-300 b/s	HDX/FDX	Joystick, Mouse	19,650
HAZELTINE	ODG-3	7738	30	Character and Line	9 Megabits/sec	....	Light Pen Keyboard	......
IBM	2250	3848	30	....	....	....	Light Pen Keyboard	120,000
IMLAC	PDS-1	3200	40	Character and Line	1.6 Mb/sec	HDX/FDX	Light Pen, Tablet, Mouse	9,620
INFORMATION DISPLAYS	IDIgraf	2048	30	Character and Line	5 Kb/sec	FDX	Light Pen, Tablet	8,000
INFORMATION DISPLAYS	IDIIOM	2048	30/20	Character and Line	50 Kb/sec	FDX	Light Pen, Trackball, Joystick	65,000
MONITOR DISPLAYS	5205	3456	50	Character and Line	454 Kb/sec	....	Light Pen, Trackball, Joystick	14,000
MONITOR DISPLAYS	8100	4000	10-60	Character and Line	3.2 Mb/sec	HDX	Light Pen	65,000
PRINCETON	PEP-801	4250/8000	Storage Tube	Character	2.4 Kb/sec	HDX/FDX	Tablet, Joystick	6,500
SYSTEMS CONCEPTS	DELTA-1/SC	8192	30	Character and Line	....	....	Light Pen, Joystick, Mouse	60,000

trying to communicate with him or is communicating with him. Echoing back from the computer requires a full-duplex operation whereas with local echoing half-duplex lines could be used for terminal-computer interconnection. However, in most common systems, characters are echoed locally--either at the terminal or at the concentrator or the store and forward switch. Block-oriented transmission is used in terminals that have editing option.

It appears that for time-shared computer applications, the use of teletypewriter terminals would dominate over any other kind of interactive terminals primarily because of reasons of economy. For every CRT terminal handled, seven to ten TTY's could be handled remotely. Needless to say, who would prefer not to have seven to ten users connected to his system rather than one. As compared with the CRT terminal estimates discussed earlier, the current TTY population is estimated to be in the range of 160,000-180,000 terminals whereas the 1974 population is estimated to be in the range of 250,000-300,000 terminals. CRT interactive displays would be used only when data/graphics is to be displayed and manipulated and a quiet terminal operation is an important requirement.

In many instances, medium-speed printers are becoming a part of the remote conversational terminals in a time-sharing computer system, a keyboard being used with the printer. The keyboard may be operated at a relatively slow speed by the human operator (10-40 bits/second), and the higher-speed printer could be used to reproduce larger quantities of data (computer output) than what a teletypewriter is capable of producing while operating at a speed of approximately 10 characters per second. Currently available medium-speed serial impact printers are available with speeds up to 40 characters per second. With the introduction of nonimpact inkjet devices, printing speeds approaching 100-250 characters per second are expected by 1974.[65]

3.2.3 The Data Stream Model

It is not possible to develop a generalized quantitative model and analysis of the stochastic communication process between user and computer in a time-shared situation due to the diversity in applications and systems. The best bet available is to discuss the nature of the communication/interaction and define the basic parameters of the interactive communication--holding time of call, think time, idle time, interburst time, intercharacter time, etc. Then one can pickup a few representative multi-access computing systems and measure the major system parameters defined earlier to gain an insight into the communication process.

Figure 15 illustrates the data stream model. A "call" (or a connect-disconnect time period) is represented as the summation of a sequence of time periods during which the user sends characters without receiving, interweaved with time periods during which he receives characters without sending. (This implies half-duplex operation. Character-by-character transmission from user to the computer implies an asynchronous transmission typical of teletypewriter terminals). The periods during which the user is sending characters to the computer are defined as "user

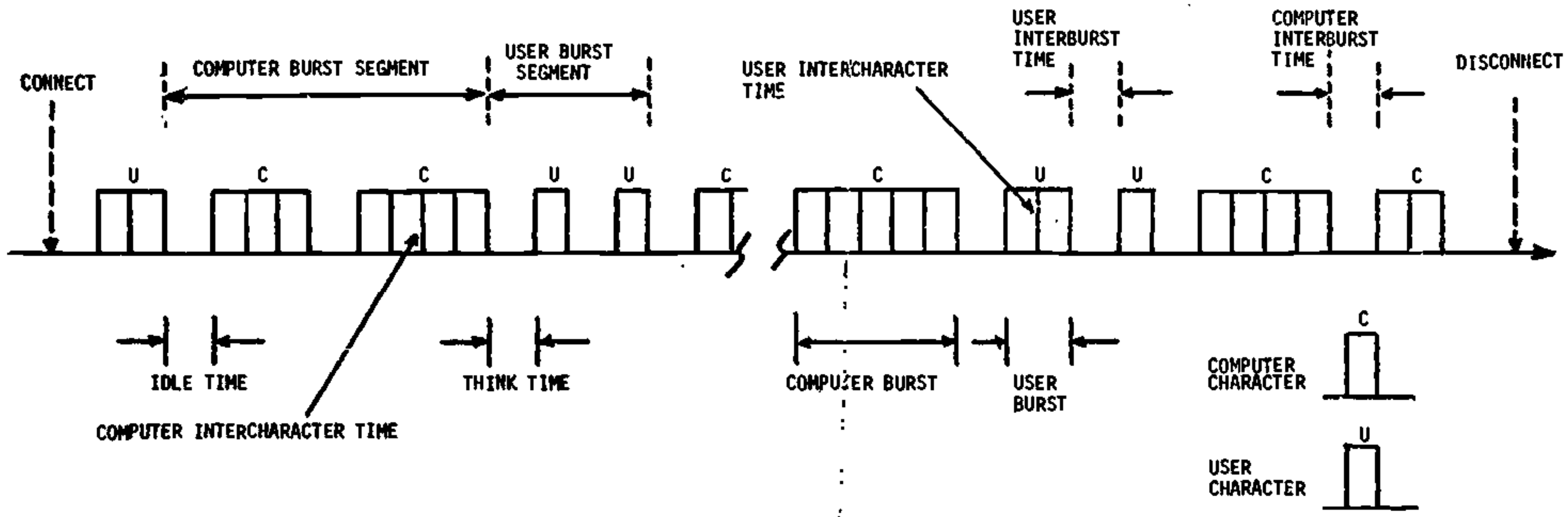


Figure 15. The Data Stream Model [Ref. 60]

burst segments". The periods during which the user is receiving characters sent from the computer are "computer burst segments". A computer burst segment begins at the end of the last character sent by the user though there may be a period of inactivity between the two burst segments--periods known as computer idle time or user think time. Think time is the time that elapses from the end of the previous computer character until the beginning of the first user character in the user burst segment. In most cases, think time is employed by the user to finish reading the previous computer output and to "think" about what to do next. The corresponding inactive period in a computer burst segment, the idle time, represents the time during which the user waits for the return of "line feed" after sending "carriage return". In non-time-shared multi-access systems with alphanumeric displays with local memory, idle-time represents the time during which the users' program is being processed or is in queue. The remaining inactive periods within a burst segment are called inter-character times and interburst times.

Two consecutive characters are defined as belonging to the same "burst" if the period of inactivity between the characters is less than one-half character width. Thus, each "burst" is the longest string of consecutive characters where the period of inactivity between any two consecutive characters is less than one-half character width; however, all the characters in a burst must, of course, be transmitted from the same party (user or computer).

The inactive period between two consecutive characters in a burst is called the user or computer intercharacter time depending upon the nature of the burst, whether it is a computer burst segment or user. Computer intercharacter time has very little spread (around the mean) whereas in teletypewriter operation, the user intercharacter time would have appreciable spread.

Five other important parameters of the data stream model are: (1) number of user bursts per burst segment; (2) number of computer bursts per burst segment; (3) number of characters per user burst; (4) number of characters per computer burst; and (5) and temporal character width--time from start to end of one character. For a given user-computer environment, a knowledge of the distributions of the parameters defined above allows calculation of some interesting measures such as holding time, percent of holding time during which the communication channel carries data, and the amount of delay introduced by the computer. For the mathematical relationships between these new measures and the major data stream parameters the reader is referred to the paper by Jackson and Stubbs.[60]

Jackson and Stubbs[60] have studied the user-computer interaction in three representative multi-access computer facilities--systems that have been labeled as A, B and C to protect the privacy of the facilities. Systems A and B have the same computer equipment and basically the same mix of user applications (scientific). System C has computer equipment different than the other two systems and its mix of user application is primarily business oriented. All three systems serve teletypewriter-like terminals. System B is rather heavily loaded compared to systems A and C, i.e., it has a larger average of busy ports. Table 7 summarizes these characteristics for systems A, B and C.

TABLE 7

CHARACTERISTICS OF SYSTEMS STUDIED BY JACKSON AND STUBBS[60]

	System A	System B	System C
Computer Type	Brand X	Brand X	Brand Y
Transmission Speed (Characters/Second)	10	10	15
Primary Application	Scientific	Scientific	Business
Load	Moderate	Heavy	Moderate

Table 8 summarizes the measured values of the model parameters. To ensure privacy of the three systems, Jackson and Stubbs[60] did not show these values on a per system basis. Rather, for each parameter, an average value $\hat{\mu}$ is given where $\hat{\mu}$ is the average of the three system averages for the given parameter. The numbers in the column entitled $\sigma_{\hat{\mu}}$ are the standard deviations of the three numbers averages in $\hat{\mu}$ for each parameter.

Table 9 summarizes the macroscopic characteristics of these data as they contribute to holding time. One can not fail to observe that the average holding time for the heavily loaded system B is considerably larger than for the lightly loaded systems A and C. The primary contribution to the holding time, in case of system B, comes from the computer delay. One also observes that user delay is a significant component of holding time in all three systems, and that combined user and computer send time averages only 31 percent of the holding time. Another important aspect is that average number of characters sent by the computer to the user is an order of magnitude greater than the number of characters sent by the user to the computer. If other parameters do not change drastically, the availability of higher transmission rates for computer outputing would effect significant reduction in average holding time. To achieve this one would have to provide asymmetric communication circuits and data sets and correspondingly higher output terminals (approx. 300 characters/second). Higher speed terminals do not pose any problem but provision of asymmetric communication circuits is certainly a major problem, particularly on a switched basis in today's telecommunications plant. Interconnection is generally provided by leased lines that significantly increase the communication cost. Since the channel activity is pretty low (31 percent on an average for the three systems that were studied), a signal activated channel would certainly provide increased communication efficiency and reduced communication costs. Further, store-and-forward type multiplexing could be used for a cluster of remote terminals to increase the communication efficiency of the channel, particularly the one linking the user with the computer.

TABLE 8

AVERAGE PARAMETER VALUES[60]

	$\hat{\mu}$	$\sigma_{\hat{\mu}}$
No. of Burst Segments	82.	37.
Think Time (sec.)	4.3	3.4
Idle Time (sec.)	.65	.48
User Interburst Time (sec.)	1.6	.90
Computer Interburst Time (sec.)	16.	25.
No. of Bursts/User Burst Seg.	11.	3.1
No. of Bursts/Computer Burst Seg.	3.3	2.8
No. of Characters/User Burst	1.1	.12
No. of Characters/Computer Burst	47.	27.
Character Width (sec.)	.089	
User Intercharacter Time (sec.)	.00021	.00023
Computer Intercharacter Time (sec.)	.00030	.000090

TABLE 9

MEAN VALUES OF HOLDING TIME COMPONENTS [60]

	System A	System B	System C
Average Holding Time τ			
Minutes	17.	34.	21.
Average User Send Time			
Minutes	0.50	0.45	0.96
% of τ	3%	1%	5%
Average Computer Send Time			
Minutes	5.7	4.5	7.5
% of τ	33%	13%	35%
Average User Delay			
Minutes	10.	12.	11.
% of τ	58%	35%	53%
Average Computer Delay			
Minutes	0.95	17.	1.5
% of τ	6%	51%	7%

3.2.4 Remote Batch Processing

Most of the popular interest in remote-access computation is centered around the use of conversational terminals for the solution of relatively small problems with low data input/output requirements. Of even greater significance to the overall educational computing scene, particularly for small and private institutions, is the trend towards shared use of computer for jobs involving significant amounts of input and output data--more than what could be conveniently entered at a conversational terminal by a human operator. Jobs in this category include virtually all traditional administrative data processing which an institution might ordinarily run on its own small-to-medium-scale computer, as well as high-volume scientific applications.

Generally, in such jobs the input data is prepared on punched cards or keyed directly onto magnetic tape and then transmitted from this media across a communication line to a large central computer. The programs to process the data are usually stored at the central computing facility, but they may also be maintained at the remote site and transmitted to the computing facility along with the input data. The output of the program is transmitted back to the remote terminal for printing on a slow-to-medium speed line printer.

Remote batch terminals, sometimes called remote job entry terminals, are generally designed in one of the two ways. In one approach, the terminal consists primarily of input/output equipment such as a punched card reader, a line printer, and perhaps a magnetic tape drive. These devices are only used for transmission to, or receipt from, the remote computer center. Since this equipment must operate over communication lines, the operating speed of the devices is limited by the capacity of the available communication lines. Therefore, a remote batch terminal of this type uses a slow-speed card reader, a slow-speed line printer, etc. the UNIVAC DCT-2000, which uses a 200-card-per-minute card reader and a 250-line-per-minute printer, is an example of this type of remote batch terminal. The second type of remote batch terminal is one which incorporates a small general-purpose computer. The primary advantage of this type of remote batch terminal is that it can be used for stand-alone data processing (i.e., it can perform certain processing without transmitting it to the remote large scale computer). The input/output peripheral equipment attached to this type of batch terminal is not designed to match the capacity of the available communication lines since the terminal operates in a stand-alone fashion. Computer-based remote batch terminals are also used because they are capable of reducing communication line costs by compressing the length of the transmitted messages (e.g., by removing blank characters or by abbreviating repeated phrases).

A remote job entry terminal basically consists of the same input/output peripherals which are normally located at the computer facility for "feeding" input to the computer and receiving output from the computer. The remote terminal is, then, simply an extension of the local line printer, card reader, or other peripheral equipment and should ideally operate at the same speeds as local peripherals. They do not today because of limitations in the intervening communication lines.

Table 10 summarizes the major characteristics and costs of some of the currently available remote batch terminals. Due to a large variation in the terminal capabilities, the cost of the terminals also varies a great deal. The lowest cost terminal could be purchased outright for some $17,000, whereas a high-speed terminal (e.g., COPE 45/COPE 1225) costs around $110,000. Communication line speed requirements range from 2,400 bits/second to 50 kilobits/second. A large number of currently available terminals come with 4,000-8,000 character memory/buffer that allows for block transmission and limited on-line program editing (when a conversational terminal is also a part of the remote batch setup). A recent survey by Datamation[80] shows that almost all terminals that are currently available are capable of making transmissions in ASCII code. Quite a few provide options for other codes (e.g., EBCDIC, XS-3, SBT, 6 bit TRANSCODE) too. All of the terminals employ some sort of error detection--primarily feedback type using parity checks and retransmissions.

Currently almost all of the remote batch terminals are linked with the central computer facility through private and leased lines because the available switched service is not capable of providing necessary higher transmission speeds with adequate error probability. Such an arrangement necessitates that one particular remote batch terminal operate with one particular computing facility and also results in higher communication costs because the users have to pay for the communication links even when they are not using it.

Unlike the conversational multi-access computing discussed earlier, there is no user think time involved in remote batch terminal-central computer communication. The channel activity factor is usually much larger than that found in interactive computing.

3.3 INTER-COMPUTER COMMUNICATIONS

Inter-computer communication is involved in situations where either remote batch terminals are built around a small computer or where a number of autonomous and specialized computing facilities, dispersed over a wide geographical area, are interconnected for resource sharing such as the ARPA network. In either case, communication differs from that found in the case of conversational terminals attended by human operators in several important aspects. A major difference is the high speed (20 kilobits/second to 5 megabits/second) at which computer communication can take place whereas a human operator can seldom take advantage of the higher data speeds. Another major difference stems from the fact that computers possess processing capabilities that are neither possessed by human beings nor devices such as tapes, discs, printers and readers which are the usual components of a remote batch terminal. Thus, computer-to-computer communication need not be on a message-by-message basis and generally involves the transmission of a group of messages which are transmitted continuously.

The future for inter-computer communications, particularly that relating to the networking of computers, depends on the availability of low-cost wideband data transmission facilities. The costs of existing facilities to fully interconnect computers nationwide either with direct

Table 10

REMOTE BATCH TERMINALS [65]

Manufacturer	Model	Keyboard	Printer (cps)	PPT Reader (cps)	PPT Punch (cps)	Card Reader (cpm)	Card Punch (cpm)	Magnetic Tape	Line Printer	Transmission Speed (bps)	Error Checking	Rental ($)	Comments
Burroughs	CER 1130	- -	- -	- -	- -	Yes	- -	- -	Yes	40,800	Parity check	1,860	Designed as remote batch terminal for B5500
Control Data	Remote Conversational Console	44-Key 64 Characters	CRT output	- -	- -	100	- -	- -	300 lpm				Newly announced data not yet available; product prototype only
CCI	CC30	61-Key 800 Characters	CRT output	- -	- -	100	100 (64 columns)	- -	300 cps	2,000, 2,400	Character parity	7,145-24,000 (purchase)	Uses standard TV for CRT output
Digitronics	500 Series	- -	- -	700	100	75	- -	24 KC	300 lpm	800, 1,200 2,400	Character per block parity; automatic retrans.		
Honeywell	Data Station	48-Key (Kleinschmidt)	37.6	120	120	100	- -			1,200	Character per message parity; automatic retrans.	200-800	
IBM	1050	53-Key 15 or 16-column keyboard	14.8	14.8	14.8	10	10	- -	- -	133.2 or 75	Character per message parity; automatic retrans.	110-600	
IBM	1978	- -	- -	- -	- -	190	91-190	- -	Yes	600, 1,200, 2,000, 2,400	Character block parity	850-1,350	
IBM	2780	- -	- -	- -	- -	400	91-355	- -	Yes	1,200, 2,000 2,400	Character block parity	700-1,200	
Mohawk	1100 Series	47 or 64-Key-up to 180 characters	15	133.3	- -	75	- -	6.25 KC	375 lpm	1,200 or 1,800	Character per message parity; bit checks on tape; automatic retrans.	245-350	
RCA	DASPAN T-R	Keyboard and dials	Yes	Yes	Yes	Yes	Yes	- -	- -	7 cps	Parity check	3,100-3,700 (purchase)	
Scientific Control	DCT-132	- -	10	300	50	300	100	- -	300 lpm	2,000, 2,400, 4,800	- -	23,500 (purchase)	Can emulate other popular remote batch terminals
Tally	Dartex	63-Key 64 Characters	16.5	120	120	75	- -	120 cps 1,600 cps	- -	1,200	Character per block parity	325	Uses incremental magnetic tape as buffer
UNIVAC	1004	- -	- -	400	110	615	200	33.3 KC	600 lpm	2,000, 2,400	Character validity; hole count-cards; character block parity; automatic retrans.	1,350-1,475	Plugboard programmable, very popular for input 1108

leased lines or dial-up facilities (with their inherent limitation to some 5.4 kbits/second speed) is prohibitive. As we will see in the next section, there has not been any decrease in the costs of communication links despite the fact that several advances have taken place in the long-distance communications whereas the costs of the central computing equipment and associated memory has been decreasing substantially. Another problem is the inadequacy of the existing plant, designed primarily to handle analog communications, to meet the needs of data-transmission and provide necessary wideband channels with the necessary quality.

Another interesting aspect that should be noted is the current pricing policy. One can buy a 10.4 kilobit/second full-duplex line from Bell System at approximately $0.40/mile/month whereas a 19.2 kilobit/second line (almost twice in speed) costs $2.50/mile/month (some six times the cost of a line with half the speed). The same disproportionate increase is also reflected in the pricing of 230.4 kilobit/second line which costs $30/mile/month--some six times the cost of a line with a 0.20 times its capacity (50 kilobit/second line costs $5.00/mile/month). A recent Network Analysis Corporation study[81] on Store and Forward Computer networks finds the larger computer networks somewhat less efficient than the smaller ones at very high output levels (18 kilobits/second +) and attributes the decrease in the efficiency of large networks with high throughputs to the limitations of the presently available equipment and long-distance communications pricing policy.

Computer-to-computer communications require full-duplex transmission facilities. It is not possible to specify the transmission rates because computer equipment can be readily designed to operate at virtually any high-speed transmission rate, limited only by the internal cycle time of the computer itself. The actual speed required will depend in general more upon the application involved than upon the physical limitation of the computer equipment. However, one can specify 50-1500 kilobits/second as the range in which computer-to-computer data transmission requirements may lie.

An important aspect of computer interconnection is related to the network topology. As a general rule, most of the computer networks would employ message switching as opposed to line switching which has been the standard switching technique for other forms of communication to obtain greater flexibility, higher effective bandwidth, and lower cost than either point-to-point leased lines or line switched service. The standard message switched service uses a large central switch with all the nodes connected to the switch via communication lines; this configuration is generally referred to as Star. Star systems perform satisfactorily for large blocks of traffic (greater than 100 kilobits per message), but the central switch saturates very quickly for small message sizes.[35] This phenomenon adds significant delay to the delivery of the message. Also, a Star design has inherently poor reliability since a single line failure can isolate a node and the failure of the central switch is catastrophic.

An alternative to the Star interconnection is the "distributed network" proposed by Baran of Rand[54] primarily for reasons of surviability. Such a system has a switch or store and forward center at every node of the network. Each node has a few transmission lines to other nodes; messages are therefore routed from node to node until reaching their final destination. The interconnection system and the design of the nodal switches becomes rather complex and expensive.

For educational computer networking, we do not believe that a distributed network is a necessity. Educational users can tolerate occasional link failures. An educational computer network could be implemented on a national scale as a star interconnection of regionally Star connected computing facilities. From the viewpoint of a satellite based interconnection via roof-top small earth terminals (explored in detail in Sections 4.4 - 4.5), the interconnection could be achieved by using addressable pre-assigned channels. Though the interconnection pattern would still be Star, there would not be a central switch that performs message switching; from the viewpoint of rooftop operation, line switching in form of demand assignment or permanent assignment of lines are the only available options.

Another major consideration is related to the protocol and standards for inter-computer communication. We think that any detailed discussion of these are beyond the scope of this paper. However, we will discuss them briefly to acquaint the readers with some of the issues involved. For implementation of a computer network, it is essential that all member computing facilities employ a common code for encoding characters, a common message format, control characters and have an established set of communications protocol, i.e., a uniform agreed-upon manner of exchanging messages between computing machines. Protocol includes data link control, acknowledgements and error recovery procedure. It seems probable that USA Standard Code for Information Interchange (USASCII OR ASCII) would be the standard code in view of the fact that it has gained wide acceptance among a large number of computer equipment manufacturers and most common carriers. There have been some questions regarding the usefulness of USASCII in a computer network environment. Alternative solutions to message formating (incompatible with USASCII) using fixed block lengths and rigid bit coding have also been proposed.[82,54] Bhushan[83], in a comprehensive study, has commented that USASCII may not be the best for one particular application, it appears to be the most reasonable for a large variety of applications. However, the message formating and communications protocol are yet to be standardized and experience with the operation of ARPA network would provide useful guidelines in this direction.

3.4 COMPUTER COMMUNICATIONS AND EXISTING TELECOMMUNICATIONS PLANT

At the moment, the prospective user of communications channels can obtain network facilities from three sources: Bell Telephone Company, Microwave Communications, Inc. (a recent entry among the common carriers), and Western Union (which, at present, itself is predominantly dependent on leasing Bell channels).

By far the largest network is that of the Bell system--a vast 300-million-channel-mile system of loaded cables, open wire, coaxial cable, and microwave facilities, with most of the long-haul transmission handled by microwave and coaxial cable. The largest share of the system is designed for analog transmission and the major portion of it for voice communication.* At the moment only a limited choice of broadband circuits are available and there are no straight direct-distance-dialing (DDD) offerings. Bell offers two options--leased line and direct-distance-dialing (DDD). With DDD, no special line conditioning is provided and the customer must take whatever circuit is provided. The data users may establish a connection up to 5.4 kilobits/second using DDD within a matter of a few seconds. Chances are, however, that the average connection will consume 10-30 seconds; during peak periods of traffic sometimes even two attempts are needed to establish connection. Such a long time to establish interconnection is unacceptable for computer-to-computer communications as the computers communicate in bursts with long period of silence between the bursts/burst segments.

Connection by leased lines results in major costs arising from communication rather than computation over long distances, while the communication link used is operated between 1-12 percent of its capacity. In addition, usually the computer-to-computer connect/disconnect requirements are of the order of few seconds whereas the current DDD charges are based upon a minimum holding time of 3 minutes--a number more suited for voice communications. Another fundamental difference between the requirements of data-transmission for time-shared systems and voice communication is the asymmetric nature of the communications required for the user of teletypewriter/alphanumeric consoles. As it was noticed in one of the previous subsections, the average amount of data transmitted from the computer to the user may be as much as an order of magnitude greater than the amount transmitted from the user to the central computer. Within the existing communications plant, it is usually not possible to arrange for different capacity channels in the two directions so that the asymmetry is a further factor in the inefficient use of the currently available communications plant.

In general, because the quality of the telecommunications circuit cannot be optimized on DDD, the data user is restricted to messages not greater than 5400 bits/second. The error rate of a typical DDD circuit is of the order of 1 error in $10^3 - 0.5 \times 10^4$ bits. For circuits with larger bandwidth and improved error performance, the user has no option other than to lease private and specially conditioned lines for operations up to 500 kilobits/second. Table 11 shows the currently available communications lines, their transmission speeds, and their costs ($ per mile per month) for intercity transmission.

---

*Because of economic factors, the Bell plant has been built so that each improvement, in general, has been compatible with the existing facilities. The basic nature of the network has remained suited for analog communication, particularly voice.

Table 11

COMMON COMMUNICATION LINES AND TRANSMISSION SPEEDS IN USE TODAY

	Speed [Bits/second]	AT&T	Western Union	Half-Duplex or Full-Duplex	Leased or Switched	Tariffs (month) zone, miles	$/mile*
Subvoice Level	45	1002	Class A	FDX/HDX	Leased	1st 100	1.40
	55	1002	Class B	FDX/HDX	Leased	next 150	0.98
	75	1005	Class C	FDX/HDX	Leased	next 250	0.56
	75		Telex	FDX	Switched	next 500	0.42
	150	1006		FDX	Leased	501 +	0.28
	150	TWX-CE			Switched		
	180		Class D	FDX/HDX			
Voice Grade	0-300	Data-Phone		FDX	Switched	1st 25	3.00
	600		Broadband Exchange, Schedule 1	FDX	Switched	next 75	2.10
	0-1200	Data-Phone		HDX	Switched	next 150	1.50
	1200	3002		HDX	Leased	next 250	1.05
	1200		Broadband Exchange, Schedule 2	FDX	Switched	501 +	0.75
	1400	3002 plus C1 Conditioning	Class E	FDX/HDX	Leased		
	2000	Data-Phone		HDX	Switched		
	2400	3002 plus C2 Conditioning	Class F	FDX/HDX	Leased		
	4800	3002 plus C4 Conditioning	Class H	FDX/HDX	Leased		
Wideband	19,200	8803		FDX	Leased	1st 250	15.00
	40,800	8801	Wideband Channel	FDX	Leased	next 250	10.50
	40,800	Data-Phone-50		FDX	Switched	501 +	7.50
	105,000	5700	Telpak C	FDX	Leased		30.00
	230,000	5700	Telpak C	FDX	Leased		30.00
	500,000	5800	Telpak D	FDX	Leased		85.00

*Where line is available both in FDX as well as in HDX, line cost is shown for HDX operation. For FDX use, add an extra 10 percent.

A detailed discussion on the inadequacies of the existing telecommunications plant for data transmission are beyond the scope of this memorandum and interested readers are referred to the SRI study on the matter.[64,84] However, we will list the seven areas where improvement is needed in the existing plant to meet the needs of data processing--areas which were identified in an SRI report[84] prepared for the Federal Communications Commission as a part of the SRI's study of the FCC Computer Inquiry (FCC Docket 16979).

* A need for rapid connect and disconnect (a few tenths of a second)
* A need for greater variety of transmission speeds and bandwidths
* A need for switched duplex connections, i.e., independent, separate paths for the two directions of transmission, in voice grade circuits
* A need for the availability of different data speeds in the two directions of transmission
* A need to reduce error rates
* A need for reduction in variability of transmission performance in the public switched network
* A need for an all-digital data transmission network

A major area of concern to educational users is the current cost of communication. The cost of a telephone line appears to have been constant over the past decade, while the cost of computers has been dropping at about 25 percent per year. If this trend continues, eventually the communication cost will become the dominant cost component of most teleprocessing systems. After all, the cost of the system as a whole can be expressed as the sum of the costs of the four elements:

$$\text{Total Cost} = \begin{bmatrix}\text{Cost of}\\ \text{Computers}\end{bmatrix} + \begin{bmatrix}\text{Cost of}\\ \text{User Terminals}\end{bmatrix} + \begin{bmatrix}\text{Cost of}\\ \text{Software}\end{bmatrix} + \begin{bmatrix}\text{Cost of Data Trans-}\\ \text{mission \& Switching}\end{bmatrix}$$

Zeidler et al. have studied the patterns of technology in Data Processing and Data Communications[64] and have found approximately 25 percent annual decrease in the computation costs. According to them, a continued decrease in cost per computer function required of the central processing unit (CPU) is expected primarily due to the advances in the state of the art in Integrated Circuit technology, basic systems design and the development of Large Scale Integration. Decrease in the cost of communication control terminals and regular conversational terminals is also expected to continue, and so is the cost of software (measured in cost per phrase). However, some caution must be interjected at this point. There is a counter trend that affects the probable cost of a teleprocessing system for a given job--the tendency of the users to want systems to be made easier to use which requires additional complex hardware as well as more complex software. System cost for a given function tends to fall less rapidly than the cost of a computation for this reason. Also, as communication costs rise as a percentage of the total cost, minimum total system cost can often be realized with more expensive computers and terminals that do more processing of the information before transmitting it. The net result is that annual cost reduction for the noncommunications component of teleprocessing systems is lower than 25 percent cost reductions in the cost of computing (measured in terms of the cost of a basic function operation in CPU). However, even 10 or 15 percent per year cost reduction is large in comparison for what is projected for communications lines.

The SRI study[64] has projected a small decrease in the communication costs for the 1970's. This combined with the fact that cost of a telephone line has been very much constant over the last decade are quite surprising when one considers the advances in terrestrial microwave, coaxial line, millimeters waveguides, and satellite communications that have taken place. The fact is that such long-haul systems have indeed dropped the long-haul portion of the telephone line cost and further reductions are expected. But the problem is the local telephone plant and associated switching system that account for over 80 percent of the cost, of even long-distance calls.[85] There is very little prospect for any significant cost reduction here. This nécessitates exploration of communication systems/techniques that bypass the existing local telephone plant and associated switching equipment. This is what exactly the newly developing specialized data-transmission/business oriented carriers like DATRAN and MCI are looking forward to. Since we are particularly interested in use of satellites, in the next section we will explore the possibility of low-cost roof-top earth-terminals for interconnecting widely dispersed computers and terminal clusters via a satellite. But before we move to the next section, we would like to discuss specialized microwave carriers in brief.

On May 26, 1971 the Federal Communications Commission issued a unanimous ruling on the definition of a communications common carrier; this ruling now permits the formation and operation of "specialized" communications common carreirs which meet certain technical and financial qualifications. This ruling is an outgrowth of an earlier ruling made in August 1969 when the FCC granted the application of Microwave Communications, Inc. to function as a communications common carrier for special communication services. The major factor behind the acceptance of the MCI application was appreciably lower cost and a highly flexible choice of channel bandwidth. However, MCI offerings are limited to leased or private lines and no circuit/message switching is involved.

Data Transmission Company (DATRAN) envisions an all-digital switched network that would initially comprise approximately 35 cities within the continental United States. The message quality objective is one error in 10^7 bits. While Microwave Communications of America (MCA) plans to achieve nationwide implementation on a sequential basis, the entire DATRAN system is planned for simultaneous operation by 1974. The DATRAN communication net is based on 4800 bits/second capacity channels of less than 2 kHz effective bandwidth. These channels may be tied together for transmitting 9600 or 14,400 bits/second; or the basic channel can be parceled into 150 bits/second sub-channels. A 48,000 bits/second leased-only service has also been proposed. These four speeds constitute the options available to the DATRAN user. Each of the 35 district switching centers would be capable of handling 1000-6000 terminals. Customers within 80 km of the district office would be serviced directly via microwave; beyond this radius, line concentrators would be used. A special feature that Datran will provide is the feasibility of broadcasting any one message to up to six subscribers. But the most attractive feature of the DATRAN switched service is the 6-second billable time as opposed to the 3-minutes on Bell System.*

*Bell System is reported to be considering a reduction in minimum connect-disconnect time to one minute.

4. SATELLITES AND COMPUTER COMMUNICATIONS

4.1 INTRODUCTION

The basic networking requirements for interactive multi-access computing can be classified as multipoint-to-point and point-to-multipoint with asymmetrical channel capacities in two directions (computer to user and user to computer)whereas those for computer interconnection can be categorized as point-to-point. The requirements for remote batch processing are similar to that of interactive multi-access computing except for the fact that interaction takes place at relatively higher speeds and the channel capacity requirements are not necessarily asymmetrical. A single relay and switching station in the sky, a satellite, overlooking a large area on the earth, has certain advantages for this kind of networking and offers distinct flexibilities in terms of geographical rearrangement of the interactive-terminal clusters and/or remote batch terminals and computers provided the terminals for communication with the satellite are colocated with the terminal clusters and/or computers.

Any arrangement that bypasses the local telephone switching plant allows users to employ the full capabilities of the high quality communication offered by the satellite. It has been estimated that a synchronous satellite communications circuit can provide error rates better than 1×10^{-7} and as good as 1×10^{-10} for data transmission. In addition, it could provide a more flexible choice of channel widths to suit the individual requirements. However, if the access to the earth-terminal is accomplished using the currently available dial network with the associated switching equipment and channels more adapted for voice communications having an error rate of 1×10^{-3} - 1×10^{-4}, the quality of the satellite part of the interconnection is of purely academic interest. The overall circuit performance cannot exceed the performance of the lowest quality component. From this viewpoint, small earth-terminals colocated at the computing facilities and shared with other kinds of satellite-based educational material delivery services such as ITV, offer an attractive alternative for computer communications.

In this section, we shall explore satellite-based computer communications using small earth-terminals and some of the problem areas. We shall not attempt any rigorous cost-benefit analysis at this stage. The latter shall be treated in one of the forthcoming memoranda in which we will explore the synthesis of economically viable alternatives for satellite-based information networking for educational institutions and users.*

---

*A major component of the satellite-based communication circuit is attributable to the earth-terminal cost and its contribution to one particular service would depend upon what other services are sharing the same earth-terminal--services such as the delivery of ETV and ITV program material, teleconferencing, etc.

4.2 THE EFFECT OF LARGE PROPAGATION DELAY ON COMPUTER COMMUNICATIONS

A minimum communication circuit length for a synchronous satellite system is 46,000-50,000 miles, made up of 23,000-25,000 miles from the transmitting earth-terminal to the satellite and an equal distance from the satellite to the receiving earth-terminal. Using a typical data communication terminal or computer system, error control is generally accomplished using a feedback technique (error detection at the receiving end and repeated retransmission until a positive acknowledgement is received). In such an operational environment, the minimum length of the transmission circuit is at least 92,000-100,000 miles for earth-terminals colocated with the computing facility and/or terminal clusters.* It would therefore take at least 0.5 second of propagation time for an impulse of energy originating at the transmitter to complete the round trip.

If a transmission rate of 20,000 bits/second were being used, a typical USASCII character would be synchronously transmitted every 0.45 millisecond. If a feedback system were utilized, the minimum delay between the blocks--the time between the transmitting end of the block and receiving the acknowledgement (positive or negative from the receiving earth-terminal or the terminal/computer communication-control)--would be a minimum of 0.5 second. The efficiency of such a system would be questionable--waiting 0.5 second before making each new transmission. In order to achieve any meaningful throughput, system designers will have to devise schemes that transmit large blocks of data, i.e., go for block transmission instead of character by character transmission that is used particularly by terminals without any local memory or buffer.

A possible solution to this dilemma, but still using feedback error correction, is continuous block transmission discussed in Appendix A. However, implementation of this technique calls for a full-duplex circuit so that acknowledgement from the receiving end can be made during the period when a new block is being transmitted. This does not impose any problems on the small earth-terminal operation that we are contemplating because as we will see later in this section, the access in most cases would be provided on an assigned PSK/FDMA basis. The only real disadvantage associated with this technique in an environment with 0.52 second propagation delay and a 20kb/second transmission rate is the large data block requirement--some 2.22×10^3 characters long for a continuous block transmission system where during the transmission of the n^{th} block, the acknowledgement for $(n-1)^{th}$ block is received.

The other alternative, and perhaps a more desirable one, is the use of forward error correction to improve the undetected error rate (see Appendix A). But the problem here is the fact that virtually all data communication terminal equipment with error control is designed for feedback type of operation. This limits the use of forward error correction between

*A terminal-cluster is comprised of all the terminals, located within the same physical facility, whose inputs and/or outputs are usually multiplexed together.

the earth-terminals and additional equipment at both ends for decoding and recoding message blocks. However, if the earth-terminals are colocated with the computing facilities and/or terminal cluster and the satellite circuit is designed for a very low error rate (10^{-7} - 10^{-10}), perhaps one could avoid any sort of error detection/correction coding for most cases.

Buckley[74] has an interesting suggestion for using existing equipment with feedback error control for satellite-based operation. He suggests a positive acknowledgement after each transmitted block which would result in essentially a continuous data transmission in smaller block format. An external "black box", which could also be a modem, would provide forward error correction. The positive acknowledgement would be generated from the "black box" upon recognition of some indication that a data block has been transmitted. This indication could be code or control-signal based and selectable by the user. Providing such a "black box" as the standard modem interface to the data terminal equipment would make all existing equipment satellite-system compatible. In brief, the disadvantages of the large propagation delay on the communication efficiency of the satellite-based circuit could be removed, to a large extent, by devising new transmission techniques.

A major effect of the large propagation delay and one that cannot be remedied is its contribution to the computer response time--an addition of approximately 1 second (when the circuit has some kind of error detection and correction whether feedback or forward). As was discussed in the previous section, a response time exceeding 1.5-2.0 seconds is usually annoying to the user in an interactive situation. Thus a 1.0 second contribution by the communication circuit necessitates an oversized and speedier computer. Most interactive multi-access could be designed to circumvent this problem but for those systems where the data entry keyboard is linked with the display terminal/teletype printer through the computer, i.e., systems with character "echoing" from the central computer as in the case of PLATO III and IV systems, the delay involved would be intolerable.

4.3 CANDIDATE SATELLITES

For an operational satellite-based computer-communication system, we consider in this memorandum the following two possibilities:

(a) A relatively high-power (55-60 dBW e.i.r.p.) dedicated educational satellite capable of small earth-terminal operation.

(b) Commercial satellite system(s) that may be authorized by the FCC and from which certain transponders or portions thereof are made available to educational users at reduced rates or free of cost.

The Federal Communications Commission (FCC), in its Report and Order in Docket 16495 in the matter of Domestic Communication Satellite Systems adopted on March 20, 1970, declared that applicants proposing multipurpose domestic communication satellite systems should discuss the terms and conditions under which satellite services will be made available for data and computer usage in meeting the educational, instructional, and administrative requirements of educational institutions. Of eight applications that were filed (see Ref. 88, Appendix B), four responded to the FCC directive by spelling out their proposed public service offerings. But only one of the applicants, the MCI Lockheed Satellite Corporation, explored areas other than PTV and ITV and specifically responded to the data communications requirements[89] for administrative data processing, computer-assisted and managed instruction, etc.

As far as operational frequencies are concerned, all the proposals are confined to uplinks in the range 5.925-6.425 GHz and/or 12.75-13.25 GHz and downlinks at 2.55-2.69 GHz, 3.7-4.2 GHz, 6.625-7.125 GHz and 11.7-12.2 GHz. All proposals contemplate using 4/6 GHz operation. The Fairchild-Hiller filing is the only one that proposes a single 2.5 GHz downlink with considerably higher e.i.r.p. (55 dBW) and allows use of low-cost terminals (approximately $2,000 per unit). The Fairchild-Hiller proposal is also the only one that proposes using the recently allocated 6.625-7.125 GHz band for TV distribution.

The major problem related to all these proposals is that none, with the sole exception of Fairchild Hiller's 2.5 GHz transponder offer, allow use of low-cost, small earth-terminals and particularly receive/transmit terminals needed for multi-access or intercomputer communication. The reasons that these proposals contemplate using larger earth-terminals are: (1) Relatively low effective radiated power (33-35.5 dBW over 34-36 MHz RF channel); (2) Use of conventional 4 and 6 GHz operation where the power flux density reaching earth is limited by a CCIR recommendation to prevent interference to terrestrial common carriers sharing the same band; and (3) The proposed rulemaking that limits the size of the ground transmitting antenna for a 6 GHz earth-to-satellite link to 25-30 foot diameter to increase orbital-spectrum communication efficiency (defined by number of channels/degree of the geostationary arc/MHz). One must not forget the fact that 4 and 6 GHz frequencies are shared with terrestrial microwave facilities and certain coordination procedures are required in earth-terminal siting if interference to and from terrestrial microwave repeaters operating on the same frequencies is to be avoided. This leads to difficulties in colocating the earth-terminal with the ground distribution headend or the interactive terminal cluster as the case may be. Colocation becomes particularly difficult, often impossible, in urban areas and requires substantial investment in microwave links connecting the far-away earth-terminal with the redistribution facility/terminal cluster.

At this stage we would like to point out that the colocation problem is much less severe in the newly allocated 2.5 GHz band and virtually nonexistent at 12-GHz. 2.5 GHz frequency band (2.500-2.690 GHz) is also allocated by the FCC to Instructional Television Fixed Service (ITFS). Any space service operating in this band would have to be designed such that it is protected from any interference from ITFS transmitters and that is does not contribute more than a certain amount of interference to the ITFS receiver. However, since the number of ITFS installations is relatively small (150-160) and the ITFS modulation is AM-VSB, the colocation problem, for a wideband FM satellite-downlink at 2.5 GHz, is nowhere as severe as in the case of 4 GHz downlink.*[90]

In brief, operation at these frequencies, particularly at 2.5 GHz for interactive communications, would permit use of low-cost earth-terminals and colocation of the satellite earth-terminal with the terminal cluster would not be difficult. For interactive data communication between a man and a machine or between machines, a 2.5 GHz downlink has certain distinct advantages as compared to a 12 GHz downlink, primarily because of low atmospheric attenuation and high DC to r.f. power conversion ratio at 2.5 GHz--factors that allow interactive communication without placing excessive demands on satellite rf output power, frequency spectrum or earth station sensitivity.[90] However, it should be noted that in the neighborhood of S-Band, only 35 MHz frequency space (2555-2690 MHz) is available for uplink transmission. If the demand for satellite-based interactive communication exceeds the communication capacity of this relatively small frequency band, the only uplinks would have to be accommodated in the 13 GHz frequency band.[90] 6-GHz uplink transmissions may soon be limited to antennae larger than 25-30 foot in diameter and thus prohibiting any small-terminal in that band.[101]

With the sole exception of a single 2.5 GHz transponder offering by the Fairchild Hiller Industries filing, all of the other offerings involve use of $50,000-$100,000 receive-only terminals with the terminal figure of merit (G/T) in the neighborhood of 23 dB or above. Thus, the earth-terminal cost becomes a major contributor to the overall communications cost. For a system in which 5,000 to 18,000 earth-terminals are contemplated (for all kinds of educational usage--CATV headend interconnection, institutional interconnection, etc.), the maximum economy lies somewhere in the systems where relatively high-power satellites serve simple and low-cost terminals and not in a situation where relatively low-powered/ satellites serve complex and very expensive earth-terminals ($6.3-0.3 million for receive/transmit type). There is a lot to be gained by rooftop operation (with limited low data-rate transmit capability) and/or CATV headend interconnection† for providing educational institutions with

---

*Power flux density restrictions at 2.5 GHz are less severe [-152 dBW/m^2/4 kHz escalating to -137 dBW/m^2/4 kHz between 5 and 25 degrees for broadcasting satellite service and -154 dBW/m^2/4 kHz escalating to -144 dBW/m^2/4 kHz between 5 and 25 degrees for fixed satellite service] than those at 4 GHz [$-(152 + \phi/15)$ dBW/m^2/4 kHz]. For 12 GHz fixed satellite service (12.5-12.75 GHz) there are no power flux density limitations at all.

†CATV or Cable TV holds great promise for certain kinds of high-volume, information delivery and resource sharing (including computer resource sharing) within its service area. Although CATV originated as a provider of a greater number of broadcast TV channels, it has grown to a point where many see it as the "Total Communication System" of the future. The latest FCC position favors implementation of two-way transmission facilities on cable and use of half of the channel capacity for non-broadcast purposes. People have already proposed hybrid TDM/FDM operation where frequency spectrum from 4 kHz to some 55 MHz (below Channel 2 of TV) is to be used for data transmission.

a variety of services including multi-access computing and computer interconnection. It allows bypassing the local telephone plant as well and eliminates the need for any large investment in dedicated interconnection between a far-away earth-terminal and the user facility.

In brief, what is needed is satellites and on-board transponders matched to the environment of a large number of earth-terminals, i.e., high-power (55-65 dBW e.i.r.p. over 34-36 MHz RF band) transponders operating in suitable frequency bands (2.5 GHz and 12-GHz). As opposed to an operation with few large terminals, it seems doubtful if any commercial operator would be willing to take the risk of providing such a specialized service; risk and uncertainties due to the greatly decentralized level of decision-making regarding the subscription to the service(s) in addition to those involved in the introduction of any new service.

The authors are of the opinion that some kind of pre-operational experience and demonstration would be needed to convince the decision makers and program participants at the local level and then educational users themselves would have to form some sort of consortium to run their own system to obtain services and facilities matched to their needs as opposed to buying multi-purpose services which often turn out to be non-optimal for one particular type of user. It is very much the same thing like the arguments for the creation of specialized carriers. However, any such development would very much depend on whether all or a very large percentage of the educational telecommunications users could be consolidated together and whether a suitable organizational framework could be devised to manage and operate such a system, given the diversity and decentralized nature of U.S. schools. These later issues have begun to be explored in a preliminary way but require much greater attention.

Thus, the role of communications satellites in providing a wide variety of educational services will very much depend upon development of dedicated system(s) capable of networking relatively smaller (3-15 foot diameter antennae) earth stations. Feldman and Kelly have emphasized this point by calling for a national commitment to high-power satellites capable of working with small ground terminals placed within population centers--that is, for a system bypassing much of present terrestrial interconnection facilities.[96] Our findings to date support their view that NASA should once again emphasize high-power communication satellite developmental activities--activities that were de-emphasized along with point-to-point communication satellite activity under Congressional direction at the time when COMSAT was established. COMSAT seems locked into Intelsat IV type of technology due to high investment cost.

Caution is required in evaluating the free offerings made by the domestic satellite system applicants. For example, today MCI-Lockheed Satellite Corporation plans to provide free use of five transponders for five years for educational users. But nobody knows what reduced rates will be charged after the initial five year period expires and during which the channel capacity occupied by educational users might well have gone unused otherwise. Besides, right now they are interested in showing public dividends as they are competing for a non-depleting but limited resource of orbital slots and operational frequencies. The educational community should also be aware of the large investments on the ground that would be needed in order to make use of the limited public service offerings. Also, it should be kept in mind that in all of the proposals, the services are not really "free" or at "reduced rates" in the overall sense. Other users will have to pick up the tab for services supplied to the educational community.

4.4 PROVIDING SMALL EARTH-TERMINALS ACCESS TO SATELLITE FOR INTERACTIVE DATA-COMMUNICATION

One of the basic questions confronting the system designer is the choice of multiple access technique(s) that permit several earth-terminals to simultaneously communicate via a common satellite-borne transponder and provide the best compromise between the earth-terminal complexity and cost, access delay, interference, and efficient utilization of the satellite transponder bandwidth. The larger the number of users sharing the satellite transponder(s), the smaller will be the channel cost per user. However, as always, there is a tradeoff between the complexity of the technique and its implementation cost and benefits derived. Beyond a certain complexity, one reaches a stage of diminishing returns. The characteristic of the communicator as well as the communicated content play an important role in the choice of the multiple access technique. For man-machine as well as machine-machine communication the channel has to have a very low error rate (10^{-6} - 10^{-10}), the communication takes place in bursts, and the channel activity factor is very small (1-12 percent as opposed to some 40 percent for voice circuits).

There are four basic multiple-access modulation techniques: Frequency Division Multiple Access (FDMA); Time Division Multiple Access (TDMA); Spread Spectrum Multiple Access (SSMA); and Pulse Address Multiple Access (PAMA). In some papers SSMA and PAMA have also been referred to jointly as Code Division Multiple Access (CDMA). Detailed discussion of these schemes can be found elsewhere.[91,98,99] In brief, one could say that FDMA, TDMA and PAMA are orthogonal modulation techniques (at least in theory). FDMA achieves orthogonality through use of non-overlapping frequency bands for each user whereas TDMA does it through the use of non-overlapping time slots for each user. PAMA does the same thing by allocating distinct time-frequency spaces or codes to each user--only one user being present in one time-frequency slot at one particular time. SSMA is a non-orthogonal multiple-access modulation technique where all the users share the same frequency-time frame all the time and use wideband phase or frequency coding to address a particular carrier for the desired receiver. The addressed receiver sees all other signals that share the same frequency spectrum as noise.

From the viewpoint of our discussions it will be beneficial to abandon any comparison based on this type of categorization and rather base the examination of the techniques on whether they provide controlled access (full-time or demand assigned basis) or random access.[92]

"Full-time" accessing refers to those techniques where each user is permanently assigned a transmit channel. To accommodate a total population of (m) users, adequate spectrum space must be available to provide at least (m) noninterfering channel assignments--exclusive frequency slots, time slots, or a combination thereof. With full-time accessing, inefficient utilization occurs when channels are idle. "Allocated" controlled accessing refers to techniques where each user is temporarily assigned a transmit channel according to the demand. Channel assignment is made on a non-interfering basis as in the case of "full-time" accessing. Such techniques allow accommodation of a total population of (m) users within a spectrum that is adequate to provide a lesser number of non-interfering channel assignments. This represents a spectrum saving. However, users can not be assured of immediate access to the satellite transponder and may have to wait until a channel becomes available. Controlled demand assignments could either be implemented with a centralized control or with a decentralized control located at each terminal. Control is needed to avoid dual- or multiple-seizure of the channels. A centralized control means an unavoidable minimum delay of 0.50 seconds in making the connection.

"Random" accessing refers to those techniques where each of (m) users is allowed to transmit at any frequency within the available spectrum at any time with no cognizance of the other user transmissions. Obviously, non-interfering operation cannot be assured. However, immediate access to the spectrum is assured. However, with random access, inefficient spectrum utilization accrues through sparse occupancy of the time/frequency plane.

Figures 16-18 show the performance of FDMA and TDMA (which could be either used in pre-assigned or demand assigned mode) and SSMA (a random access technique). In each case, the performance is evaluated in terms of the number of users vs. $(C/T)_{Dn}$ where $(C/T)_{Dn}$ represents the ratio of downlink carrier power (over the entire transponder bandwidth and hence for all users) to earth-terminal system noise temperature. Curves are plotted for a uniform users data rate of 20 kilobits/second, transponder bandwidth of 40 MHz, 4-ϕ Coherent Phase Shift Keying modulation technique*, and an error rate of 1 in 10^6. FDMA performance curve assumes a-23 dB cochannel interference, -23 dB intersymbol distortion, an intermodulation to carrier power ratio of -16 dB (for a transponder TWT output back-off of -5 dB for a large number of carriers), and a 0.5 dB PSK demodulator implementation loss. (E/N_0) requirement for 4-ϕ CPSK in every case is taken as 14.6 dB/Hz for an error rate of 1 in 10^{-6}. We have also calculated the performance of SSMA (Random Access) for 16-ϕ coded CPSK to show the increased access handling capacity. For the derivation of the performance equations the reader is referred to Ref. 91.

It is obvious from Figures 16-18 that TDMA is more power efficient than FDMA while both, at least theoretically, provide almost the same number of accesses for a given RF bandwidth and modulation technique. For a 40 MHz wide satellite-borne transponder, both techniques can

---

* 4-ϕ CPSK was assumed as a compromise between the bandwidth and power requirements and receiver complexity.

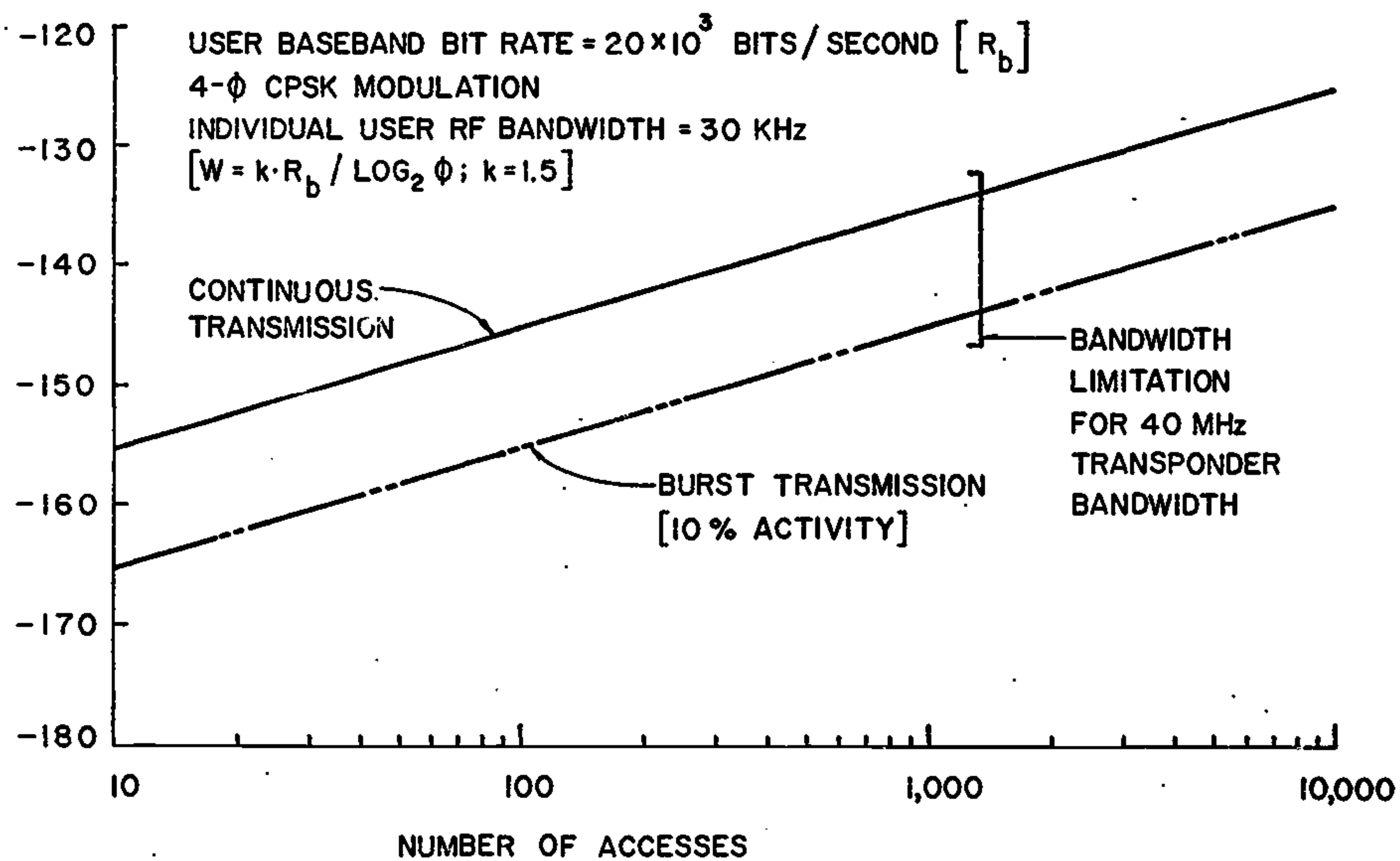


FIGURE 16. FDMA PERFORMANCE--NUMBER OF ACCESSES VS $[C/T]_{Dn}$

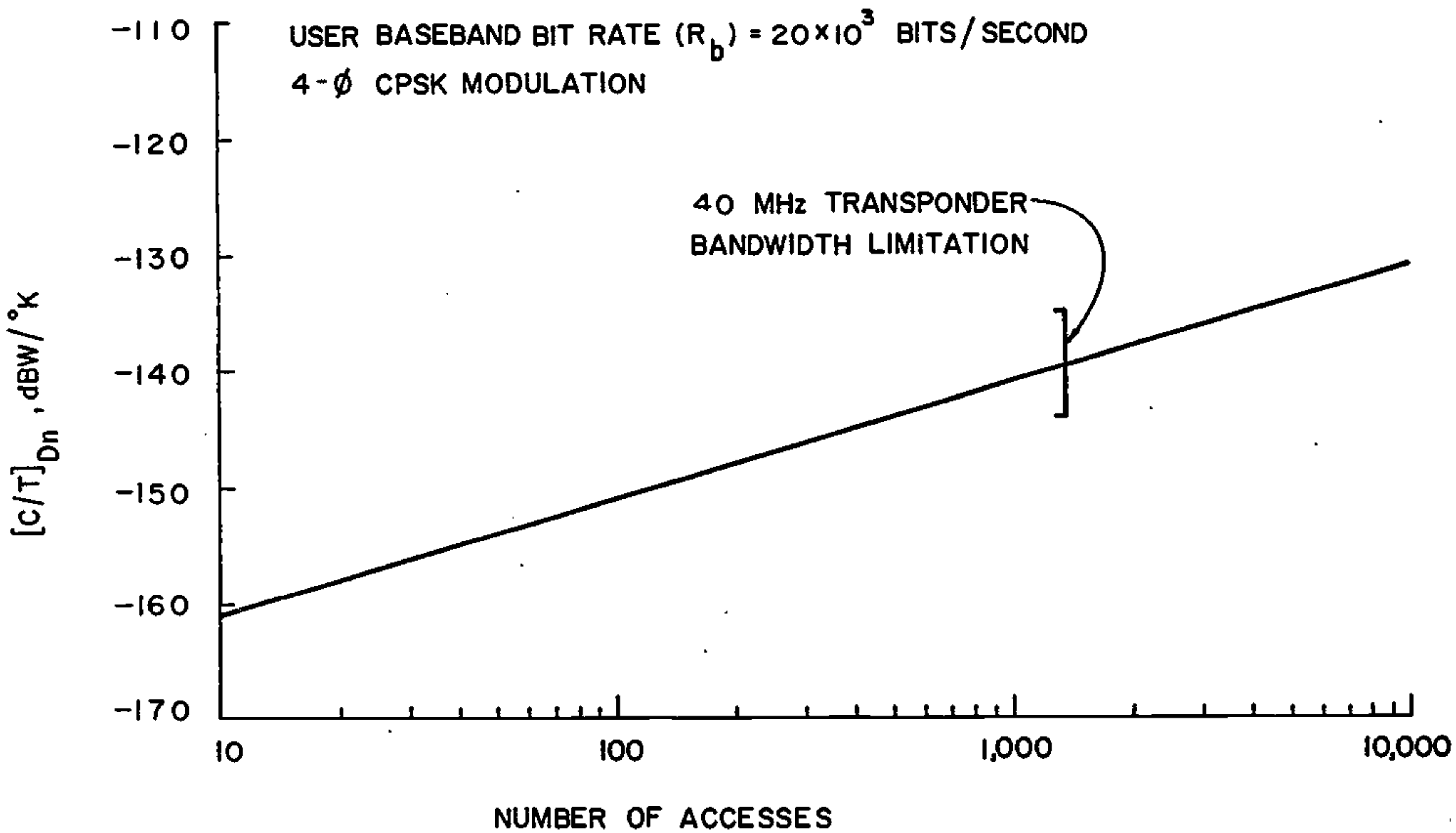


FIGURE 17. TDMA PERFORMANCE--NUMBER OF ACCESSES VS $[C/T]_{Dn}$

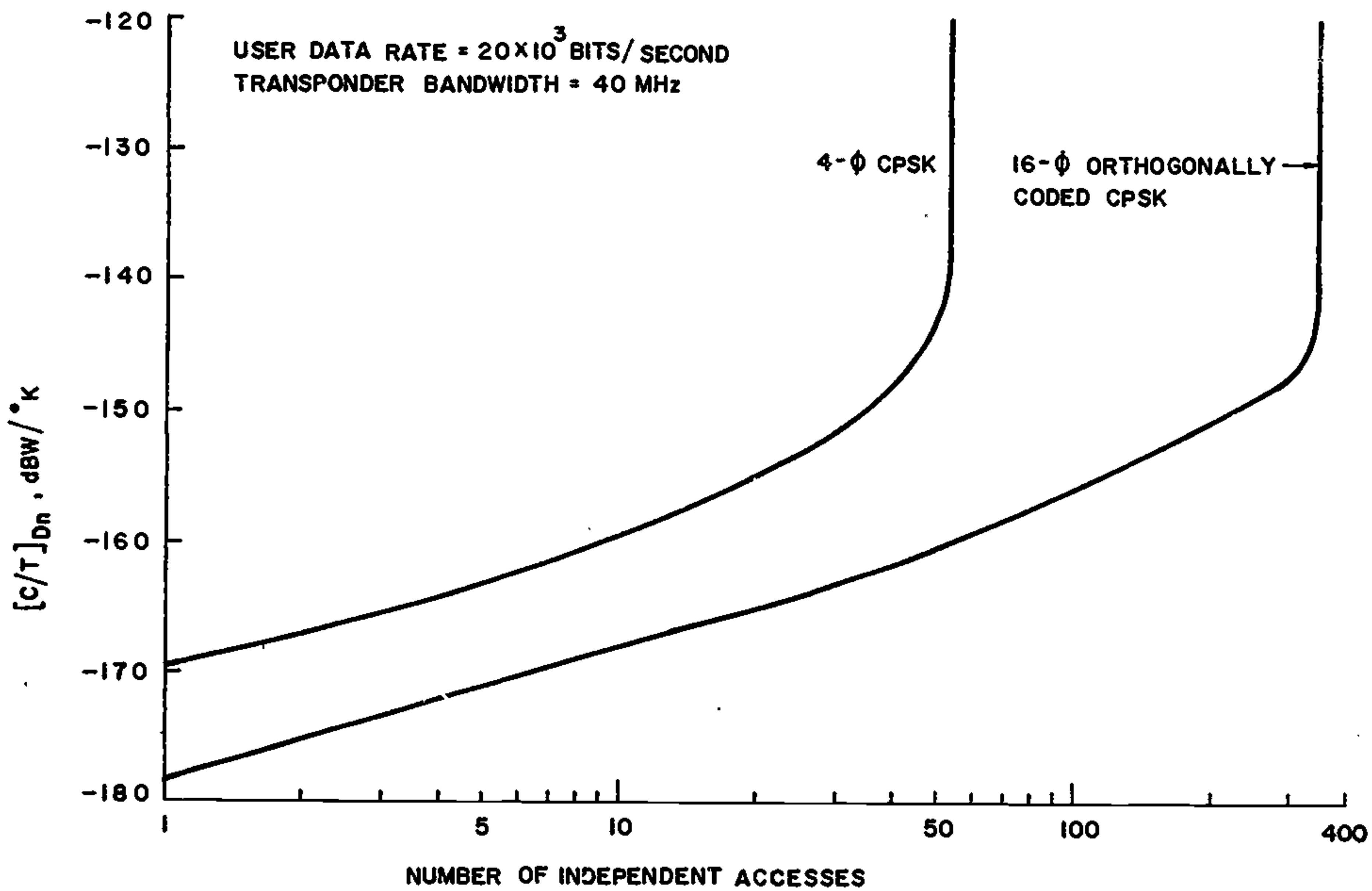


FIGURE 18. RANDOM ACCESS (SSMA) PERFORMANCE -- NUMBER OF ACCESSES VS $[C/T]_{Dn}$

accommodate some 1300 simplex channels. However, TDMA allows operation with less-sensitive ground terminals under equal conditions. But when FDMA is operated under burst modes, i.e., when the carrier is activated only in the presence of a signal, it provides a comparable performance even in terms of earth-terminal sensitivity requirements. The only disadvantage of FDMA under small terminal situation is the power coordination of the uplink needed to maintain the signal strength at the satellite transponder input within 0 ± 0.75 dB to ensure proper power sharing among the large number of independent carriers within the transponder bandwidth. Power coordination requirement would be quite severe at 13 GHz due to localized rain-induced heavy, but infrequent, attenuations. With a S-Band uplink power coordination would not be difficult to maintain.

Random access techniques (Figure 18) provide a graceful system degradation but a very limited number of accesses as compared with either FDMA or TDMA. When the bandwidth is not at a premium (with very small number of accesses), the earth-terminal sensitivity requirements are smaller than those for TDMA as well as FDMA. However, the complexity is great in SSMA implementation and the cost is high, particularly when large level modulation techniques such as 16-ϕ coded CPSK are to be used to increase the number of independent accesses. A 40 MHz satellite transponder can handle something like 346 accesses at one given time with 16-ϕ coded orthogonal CPSK. With low-channel activity users, particularly for the burst type of communication experienced in computer communications--some 10% channel activity on an average during holding time--the technique allows a more efficient spectrum utilization than pre-assigned TDMA or FDMA. However, the cost is prohibitive for application in the operational environment that we have been talking about--a large population of low-cost earth-terminals with limited low data-rate transmission capability.

For computer communications, demand assignment of circuits does not seem to be all that attractive from the viewpoint of small-terminal operation. It is not only the average time between the circuit holding periods that will be the major contributor to the overall channel idleness but also the idle periods during the holding period itself which are the major contributors to the overall channel inactivity. The delays involved in controlled demand access make any demand assignment based on the signal activity and not the total holding period unsuitable for interactive data-communication--whether the interaction is between man and machine or among machines.

We propose that in initial periods of system operation, access be given on a pre-assigned PSK/FDMA basis and a simple "request acknowledge"-based common-channel signalling be used to provide variable destination type of interconnection to computer installations, which are used less frequently. It is further recommended that a burst type of communication be used in which the carrier is switched off during absence of any signal. Burst nature of transmission will require a lesser number of carrier signals to be processed at the transponder at any given instance. This means that the transponder output power would be spread over only the active signals, thus lowering the $(C/T)_{Dn}$ (receiving system sensitivity) requirements for a given e.i.r.p.*

4.5 ECONOMICS OF SATELLITE-BASED COMPUTER COMMUNICATIONS

Earlier in this section we said that the detailed comparative economics of satellite-based computer communications will be dealt with in the second phase of our work (Systems Synthesis) where we try to synthesize the alternatives and study their sensitivities to various system parameters. However, at this stage some comments on it are in order.

In an earlier memorandum on Computer-Assisted Instruction and its Telecommunications Requirements[3], we discussed Jamison's paper[95] on the communication economics of interactive instruction for rural areas. In his paper, Jamison evaluated the tradeoffs between terrestrial and satellite-based communication between a central computing facility and clusters of low data rate teletypes. He found that use of communication satellites is economically viable over long distances (200-300 miles) when a large number of clusters are to be served. Jamison assumed single purpose low-cost terminals for his computation. For general purpose interactive computing and with the use of multi-purpose low-cost earth-terminals like the one needed at the CATV headend for CATV interconnection[97], we expect the communication offered by satellites to be available at costs comparable to those available from terrestrial common carriers for distances larger than 70-90 miles and above depending upon the data rate requirements and terminal population. However, this kind of a crossover distance range still limits the use of satellites for directly delivering general purpose interactive computing as well as raw batch processing power to small and isolated schools.

The other areas in which we expect satellites to demonstrate distinct economic advantage in the operational environments that we have been discussing, that is, high-power satellite(s) operating in conjunction with a large number of low-cost multi-purpose earth-terminals are interconnection of high data-rate (20 kilobits/second and above) graphical interactive terminals with specialized computing facilities, and interconnection of widely distributed computers and regional computing networks.

In the previous section, we demonstrated that in the PSK/FDMA mode, a satellite transponder with 40 MHz bandwidth can handle some 1,300 20 kilobit/second simplex channels. Let us assume that in actual practice the number is limited to 1,200. This means 600 full duplex circuits per

---

*We would like to point out that the advantages of the burst transmission would be realized primarily in the case of remote batch computing, computer interconnection, and interconnection of regional networks. For multi-access interactive computing with teletypewriter and low-data-rate alphanumeric display consoles, the output of all the terminals at a particular terminal cluster will probably be multiplexed together and the output of the multiplexer will usually always have the same bandwidth occupancy (in FDM) or the same bit rate (in TDM).

transponder. From the advanced technology data now available, one can safely extrapolate the annual cost of a high-power transponder (55-58 dBW e.i.r.p.) to be $1.5 million with a satellite design life-time of seven years*. This means that the satellite transponder cost per 20 kilobit/second FDX circuit would be $204 per month. Assuming a cost of $25,000 for the earth-terminal and a ten year life-time, one could allocate a $200 per month earth-terminal contribution to the 20 kilobit/second circuit. Since each circuit needs two earth-terminals to complete it, the total earth-terminal contribution will be $400 per month. This makes the estimated total cost of a 20 kilobit/second circuit to be $604 per month.

Current AT&T inter-exchange charges for a 19.2 kilobit/second FDX circuit (No. 8803--Table 11) are of the order of $15 per mile per month for the first 250 miles. In addition, AT&T charges approximately $800 per month per node for interfacing. Even if one, for the time being, neglects the interfacing charges (not an insubstantial amount as compared to the circuit cost), satellite-based interconnection would be cost-effective for distances greater than 40.5 miles. We expect that interfacing could be achieved with much smaller investment than that which is currently charged by AT&T. This would further lower the crossover distance to some 30 miles. Assuming that the newly developing specialized common carriers such as MCI and Datran will be able to offer rates some 0.5 times of those currently available, the small-terminal based satellite interactive interconnection would still remain viable over 60-70 miles. One of the greatest advantages of a satellite-based interactive networking that bypasses the existing telephone plant would be the flexibility in the choice of channel widths and ease in operation with high data rate channels (1 Megabit/second and above), channels that will be difficult or impossible to obtain from telephone companies locally.

*In current applications for domestic satellite authorization, the annual cost of a satellite transponder is in the range of $375,000 - $620,000. Low-capacity satellites proposed by Hughes Aircraft (Thor-Delta launch) can provide a transponder with 33-34 dBW e.i.r.p. for $375,000 per year whereas an equivalent transponder on a COMSAT satellite (Atlas Centaur launch) is of the order of $615,000 per year (both figures include operational and maintenance costs). Our cost, some 2.5 times the high-bound of those reflected in the current domestic applications, is quite reasonable for an e.i.r.p. of 55-58 dBW; it is certainly not on the low side.

5. REFERENCES

1. Levien, Roger E.: "Instructional Uses of the Computer in Higher Education", Paper P-4600, The RAND Corporation, Santa Monica, California, (March 1971).

2. Silvern, L. C.: "CAI is an Expanding Universe of Educational Methodology", Chapter 7 in Conversational Computers by W. D. Orr, John Wiley, London, (1968).

3. Singh, J. P. and Morgan, R. P.: "Computer-Based Instruction: A Background Paper on its Status, Cost-Effectiveness, and Telecommunications Requirements", Program on Application of Communications Satellites to Educational Development, Internal Memo. IM-71/3, Washington University, St. Louis, Missouri, (April 1971).

4. Coleman, J. S. and Karweit, N. L.: "Multi-Level Information Systems in Education", Paper P-4377, The RAND Corporation, Santa Monica, California, (June 1970).

5. Levien, R. E. et al.: "The Emerging Technology: Instructional Uses of Computers in Higher Education", Report R-503-CCOM/NSF/RC, The RAND Corporation, Santa Monica, California, (1971).

6. Evans, D. C.: "Computer Logic and Memory", in Information (A Scientific American Book), W. H. Freeman & Company, San Francisco, California, (1966).

7. Computer Yearbook and Directory, 2nd Ed., American Data Processing, Inc., Detroit, (1968).

8. Fano, R. M. and Corbato, F. J.: "Time-Sharing on Computer", in Information (A Scientific American Book), W. H. Freeman & Company, San Francisco, California, (1966).

9. Hayes, Robert M. and Becker, J.: "Handbook of Data Processing for Libraries", Becker and Hays, Inc. (A Subsidiary of John Wiley), New York, (1970).

10. Overhage, C. F. J. and Harman, R. J.: "INTREX--Report of a Planning Conference on Information Transfer Experiments", MIT Press, Cambridge, Massachusetts, (1965).

11. "Computer-Based Vocational Guidance Systems", U. S. Office of Education, OE-25053, Superintendent of Documents, Washington, D. C., (1969).

12. Flanagan, John C.: "One-Year Follow-Up Studies", University of Pittsburg, (1966).

13. Clayton, J. C.: "Information Systems for Educational Policy and Administration", The RAND Corporation, P-4384, Santa Monica, California, (June 1970).

14. Blackwell, F. W. et al.: "Educational Information System Design--A Conceptual Framework", The Rand Corporation, P-4411, Santa Monica, California, (August 1970).

15. Goodlad, J. I. et al.: "Computers and Information Systems in Education", Harcourt, Brace, and World, Inc., New York, (1966).

16. Yarbrough, L. E.: "The Florida Plan for a Statewide Educational Management Information System", J. Association Educational Data Systems, September 1969, pp. 1-9.

17. Doyle, F. J. and Goodwill, D. Z.: "An Exploration of the Future in Educational Technology", Bell Canada, Montreal, (1971).

18. Darby, Jr., C. A. et al.: "Survey of Computing Activities in Secondary Schools", American Institutes for Research, Washington, D. C., (October 1970).

19. Bangs, F. K. et al.: "Automated Data Processing for Education--Curricular Implications", Management Information Services, Detroit, (1970).

20. Lessinger, L. M.: "Every Kid a Winner: Accountability in Education", Simon & Schuster, New York, (1971).

21. Bushnell, D. and R. L. Howe: "A Report of an Experiment--The State Pilot Project in Educational Data Processing", Department of Education, State of California, (May 20, 1964).

22. Arthur D. Little, Inc.: "An Analysis of Regional Planning Agencies in California Funded by ESEA Title III: A Study of the Regional Data Processing Centers, Vol. 3, (1968).

23. Comstock, G. A.: "National Utilization of Computers" in The Emerging Technology: Instructional Uses of the Computers in Higher Education, (Ed., Roger E. Levien), Report R-503-RC, The Rand Corporation, Santa Monica, California, (1971).

24. Comstock, G. A.: "The Computer and Higher Education in California", in The Emerging Technology: Instructional Uses of the Computers in Higher Education, (Ed. Roger E. Levien), The Rand Corporation, Santa Monica, California, (1971).

25. Hamblen, John W.: "Using Computers in Higher Education--Past Recommendations, Status and Needs", Paper presented at Fall Joint Computer Conference, Las Vegas, Nevada, (December 1969).

26. Hamblen, J. W.: "Inventory of Computers in U.S. Higher Education", Southern Regional Education Board, Atlanta, Georgia, (1969).

27. "Computers in Higher Education", Report of the President's Science Advisory Committee, The White House, Washington, D. C., (February 1967).

28. Hamblen, J. W.: "Computers in Higher Education", Southern Regional Education Board, Atlanta, Georgia, (1967).

29. Greenberger, M.: "A Quick History (In Four Questions and Phases) of the Development of Computing in Higher Education", EDUCOM, Summer 1971, Vol. 6, No. 2.

30. Knight, K. E.: "A Study of Technological Innovation--The Evolution of Digital Computers, Ph.D. Dissertation, Carnegie Institute of Technology, (November, 1963).

31. LeGates, J.: "Educational Computer Communication", Remarks made at the Conference on Satellites for Education, Washington University, Saint Louis, Missouri, (July 19-20, 1971).

32. Duggan, M. A., Edward F. McCartan, and Manley R. Irwin, Eds.: "The Computer Utility: Implications for Higher Education", Heath Lexington Books, Lexington, Massachusetts, (1970).

33. Heart, F. E., Kahn, R.E., et al.:"The Interface Message Processor for the ARPA Network", Spring Joint Computer Conference 1970 Proceedings.

34. Kleinrock, L.:"Analytic and Simulation Methods in Computer Network Design", Spring Joint Computer Conference 1970 Proceedings.

35. Roberts, L. G. and Wessler, B. D.:"Computer Network Development to Achieve Resource Sharing", Spring Joint Computer Conference 1970 Proceedings.

36. Rutledge, R. M., Varian, L. C., et al.: "An Interactive Network of Time-Sharing Computers", Carnegie-Mellon University, Pittsburg, Pennsylvania (1970).

37. Freeman, D. N. and Pearson, R. R.:"Efficiency vs Responsiveness in a Multiple Service Computer Facility", Proceedings 1968 ACM National Conference (1968).

38. Brooks, F. P. et al: "Organizational, Financial, and Political Aspects of a Three-University Computing Center", Proceedings of the 1968 IFIP Congress (1968).

39. Nielsen, N. R.: "The Merit of Regional Computing Networks", Communications of the ACM, May 1971 (Vol. 14, No. 5).

40. Levien, R. E. and C. Mosman: "Computer Services on Campus", in The Emerging Technology: Instructional Uses of the Computer in Higher Education, The Rand Corporation, R-503-RC, Santa Monica (1971).

41. Irwin, Manley R.: "The Computer Utility", Datamation, November 1966, p. 23.

42. Kolker, R. J. et al: Time-Sharing Services-Region I (New England and Mid-Atlantic States), Modern Data, January 1971.

43. Kolker, R. J. et al.: "Time-Sharing Services--Region II (South Atlantic and South Central States)", Modern Data, July 1971.

44. Baur, W. F. and Richard H. Hill: "Economics of Time-Shared Computing Systems", Datamation, November 1967 and December 1967.

45. Gold, Michael M.: "Time-Sharing and Batch-Processing: An Experimental Comparison of Their Values in a Problem Solving Situation", Communications of the ACM, Vol. 12, No. 5 (May 1969).

46. Sharpe, W. F.: "The Cost and Effectiveness of Computer Systems", in The Economics of Computers, The Rand Corporation, R-463-PR, Santa Monica, California (August 1969).

47. Knight, K.: "Evolving Computer Performance 1962-67", Datamation, January 1968, pp. 31-35.

48. Solomon, M.B.: "Economies of Scale and the IBM System/360", Communications of the ACM, June 1966, pp. 435-440.

49. Cox, Jr., J. R.: "Economy of Scale and Specialization in Large Computing Systems", Monograph 93, Biomedical Computer Laboratory, Washington University School of Medicine, Saint Louis (November 1968).

50. Bhushan, Abhaya K.: "Guidelines for Minicomputer Selection", Computer Design, April 1971.

51. Hrones, J. A.: "Computing in Higher Education", EDUCOM, Summer 1971 (Vol. 6, No. 2).

52. Seven, M. J. et al.: "A Study of User Behavior in Problem Solving with an Interactive Computer", The Rand Corporation, R-531-NASA, Santa Monica, California (April 1971).

53. Bhushan, A. K. et al.: "Recommendations for an Inter-Computer Communication Network for MIT", Project MAC Memorandum MAC M 355, Massachusetts Institute of Technology, Cambridge, Mass. (July 1967).

54. Baran, Paul, et al.: On Distributed Communications, Vol. I, RM-3420-PR; Vol. II, RM-3013-PR; Vol. III, RM-3578-PR; Vol. IV, RM-3638-PR; Vol. V, RM-3097-PR; Vol. VI, RM-3762-PR; Vol. VII, RM-3763-PR; Vol. VIII, RM-3764-PR; Vol. IX, RM-3765-PR; Vol. X, RM-3766-PR; Vol. XI, RM-3767-PR; Vol. XII, RM-5067-PR; Vol. XIII, RM-5174-PR, The Rand Corporation, Santa Monica, California (August 1964).

55. Lesser, R. C. and A. Ralston: "The Development of a Multi-Campus Regional Computing Center", Information Processing 1968, Proceedings of 1968 IFIP Congress, North-Holland Publishing Company, Amsterdam (1969).

56. Scherr, A. L.: "An Analysis of Time-Shared Computer Systems", Thesis MAC-TR-18, Project MAC, Massachusetts Institute of Technology, Cambridge (Jun3 1965).

72. Doll, D. R.: "Controlling Data Transmission Errors", Data Dynamics, July 1971 (Vol. 13, No. 7).

73. Lohse, E. L. (Ed.): "Proposed USA Standard: Data Communication Control Procedures for the USA Standard Code for Information Interchange", Communications of the ACM, Vol. 12, No. 3 (March 1969).

74. Buckley, J. E.: "Satellite Communication", Computer Decision, Vol. 10, No. 7 (July 1971).

75. Lynch, T. J.: New Developments in Convolution Encoding and Decoding, NASA X-750-71-139, Goddard Space Flight Center (National Aeronautics and Space Administration), Greenbelt, Maryland (April 1971).

76. Ralphs, J. D.: "Limitations of Error-Detection Coding at High Error Rates", Proceedings IEE (U.K.), Vol. 118, No. 3/4 (March/April 1971).

77. Peterson, W. W.: Error-Correcting Codes, MIT Press and John Wiley & Sons, Inc., New York (1961).

78. Massey, J. L.: Threshold Decoding, MIT Press, Cambridge, Mass. (1963).

79. Wozencraft, J. M. and B. Reiffen: Sequential Coding, Technology Press and John Wiley & Sons, New York (1961).

80. Theis, D. J. and L. C. Hobbs: "Trends in Remote-Batch Terminals", Datamation, September 1, 1971.

81. Howard, Frank: Research in Store and Forward Computer Networks, Network Analysis Corporation, Glen Cove, New York (January 1971). AD 719 416.

82. Bartlett, D. et al.: "A Digital Communications Network for Computers Giving Rapid Responses at Remote Terminals", Conference of ACM on Operating Principles, Gatlinburg, October 1967.

83. Bhushan, A. K. and R. H. Stotz: "Procedures and Standards for Inter-Computer Communications", Spring Joint Computer Conference 1968.

84. Dunn, Donald A.: "Policy Issues Presented by the Interdependence of Computer and Communications Services", Report 7379B-1, Stanford Research Institute, Menlo Park, California (Feburary 1969).

85. Dunn, Donald A.: "The FCC Computer Inquiry", Datamation, October 1969.

86. Solomon, M. B.: "Economies of Scale and Computer Personnel", Datamation, March 1970.

87. Weeg, G. P.: "The Role of Regional Computer Networks" in Computers in Instruction: Their Future for Higher Education, (Ed. R. E. Levien), Report R-718-NSF/CCOM/RC, The Rand Corporation, Santa Monica, California (July 1971).

88. Singh, J. P. and R. P. Morgan: "Educational Electronic Information Dissemination and Broadcast Services: History, Current Infrastructure, and Public Broadcasting Requirements", Memorandum No. 71/3, Washington University Program on Application of Communications Satellites to Educational Development, Washington University, Saint Louis, Missouri (August 1971).

89. Krause, L. I.: "Satellite Communications for U.S. Schools--A Proposed Public Service Offerings by Private Business", Stanford Research Institute, Menlo Park, California (Feburary 1971).

90. Singh, J. P.: "Operating Frequencies for Satellite Services for Education", Memorandum 71/10, Washington University Program on Application of Communications Satellites to Educational Development, Saint Louis, Missouri (October 1971).

91. Singh, J. P.: "Multiple Access Considerations for an Indian Domestic Telecommunications Satellite System", Technical Report EE-COM-11, Department of Electrical Engineering, Indian Institute of Technology Kanpur, Kanpur, India (July 1969).

92. McGregor, D. N. et al.: "Demand Assignment Multiple Access Study", NASA Contract No. NAS 5-21144, Computer Sciences Corporation, Falls Church, Virginia (December 1970).

93. Dooley, G. F. and P. C. Jain: "Time Division Access Feasibility Study--Modulation and Synchronization Considerations", NASA Contract No. NASW-1216, Communication Systems, Inc., Falls Church, Virginia (October 1967).

94. Blasbalg, H.: "A Comparison of Pseudo-Noise and Conventional Modulation for Multiple-Access Satellite Communications", IBM Journal, July 1965.

95. Jamison, D. et al.: "Communication Economics of Interactive Instruction for Rural Areas", Stanford University, Stanford, California (Unpublished Paper), March 1971.

96. Feldman, N. E. and C. M. Kelly: "The Communication Satellite--A Perspective for the 1970's", Astronautics and Aeronautics, Vol. 9, No. 9 (September 1971).

97. Rosenbaum, F. J., J. P. Singh, B. Newman: "Preliminary Design of a 12-GHz Low-Cost Multi-Channel TV Receive-Only Earth-Terminal", Memorandum 71/8, Washington University Program on Application of Communications Satellites to Educational Development, Washington University, Saint Louis, Missouri (October 1971).

98. Wittman, J. H.: "Categorization of Multiple Access/Random Access Modulation Techniques", IEEE Trans. on Com. Tech., Vol. COM-15, No. 5, October 1967.

99. Schwartz, J. et al.: "Modulation Techniques for Multiple Access to a Hard-Limiting Satellite Repeater", Proceedings IEEE, Vol. 54, No. 5, May 1966.

100. Magil, D. T.: "Multiple Access Modulation Techniques", In Progress in Astronautics and Aeronautics, Vol. 19, Academic Press, New York (1966).

101. Hinchman, W. R.: "Issues in Spectrum Resource Management", In The Future of Satellite Communications--Resource Management and the Needs of Nations, The Twentieth Century Funds, New York (1970).

APPENDIX A

INFORMATION CODING AND ERROR CONTROL

It is well known that with n binary pulses, one can, in theory, code 2^n different combinations into these pulses. The "characters" that are sent by data transmission from the remote terminal to the computer often contain five, six, seven or eight bits. Five bits can give 32 different characters, six bits 64, seven bits 128, and eight bits 256. A seven-bit code is thus used a range of up to 128 characters. It would not always transmit 128 characters because some of the combinations are reserved for special purpose control characters (such as blank, letters shift, figures shift, space, carriage return, line feed, delete, restore, etc.) and some bit positions are used for error control, e.g., many data transmission codes use an extra bit, called a parity bit, in each character for checking purposes--a technique sometimes called vertical redundancy checking.[70,72]

Today a large number of data transmission codes are in use--CCITT standard five bit telegraphy code, codes referred as Binary-Coded Decimal with six or sometimes even seven bits per character, N-out-of-M codes (a common example being 4-out-of-8 codes), American Standards Institution's ASCII 7-bit code that permits double shift printing and has enough control characters for most purposes, etc.[70] Individual machine designers often find their own reasons for employing their own coding system. However, use of widely different codes does not permit users to gain access to different computer systems through switching; often one particular terminal is permanently tied to one particular system. Any desire for switched access needs standardization of the transmission codes for its fulfillment.

The American Standards Institution (ASI), CCITT, and other national bodies have given much thought to the problem of standardization of data-transmission codes. The requirements of different users conflict considerably, so there are difficulties in agreeing upon common standards. The American Standards Institution, however, has standardized the U.S. ASCII (Figure 1).[70,73] It is a seven-bit code; an eighth bit can be added if desired as a parity check. Since its inception, it has come into wide acceptance in telegraphy and data transmission in the United States. Several of the computer manufacturers are using it. It will be of value to have also a six-bit and eight-bit standard codes. ASI is working on it but so far no such codes have been accepted. However, several variations of ASCII codes exist in six-bits--IBM uses a six-bit code that contains a subset of the characters in the seven-bit ASCII code.

Transmission of information over non-ideal, real-world, noisy communications channels results in the introduction of errors in the original intelligence at the channel output. For most applications, three basic ways of coping with transmission errors are available:

- Ignore the errors
- Detect errors and retransmit the data
- Employ forward error correction (FEC) methods

Bits b7 b6 b5					0 0 0	0 0 1	0 1 0	0 1 1	1 0 0	1 0 1	1 1 0	1 1 1
b4	b3	b2	b1	Row ↓ Column →	0	1	2	3	4	5	6	7
0	0	0	0	0	NUL	DLE	SP	0	@	P	`	p
0	0	0	1	1	SOH	DC1	!	1	A	Q	a	q
0	0	1	0	2	STX	DC2	"	2	B	R	b	r
0	0	1	1	3	ETX	DC3	#	3	C	S	c	s
0	1	0	0	4	EOT	DC4	$	4	D	T	d	t
0	1	0	1	5	ENQ	NAK	%	5	E	U	e	u
0	1	1	0	6	ACK	SYN	&	6	F	V	f	v
0	1	1	1	7	BEL	ETB	'	7	G	W	g	w
1	0	0	0	8	BS	CAN	(	8	H	X	h	x
1	0	0	1	9	HT	EM	)	9	I	Y	i	y
1	0	1	0	10	LF	SUB	*	:	J	Z	j	z
1	0	1	1	11	VT	ESC	+	;	K	[	k	{
1	1	0	0	12	FF	FS	,	<	L	\	l	¦
1	1	0	1	13	CR	GS	-	=	M	]	m	}
1	1	1	0	14	SO	RS	.	>	N	^	n	~
1	1	1	1	15	SI	US	/	?	O	_	o	DEL

Figure 1. <u>USA Standard Code For Information Interchange (ASCII)</u>

Ignoring errors is sensible in applications which include substantial amounts of English language texts or voice or other types of messages with sufficient inherent redundancy. For data transmission, control of errors is of vital importance.

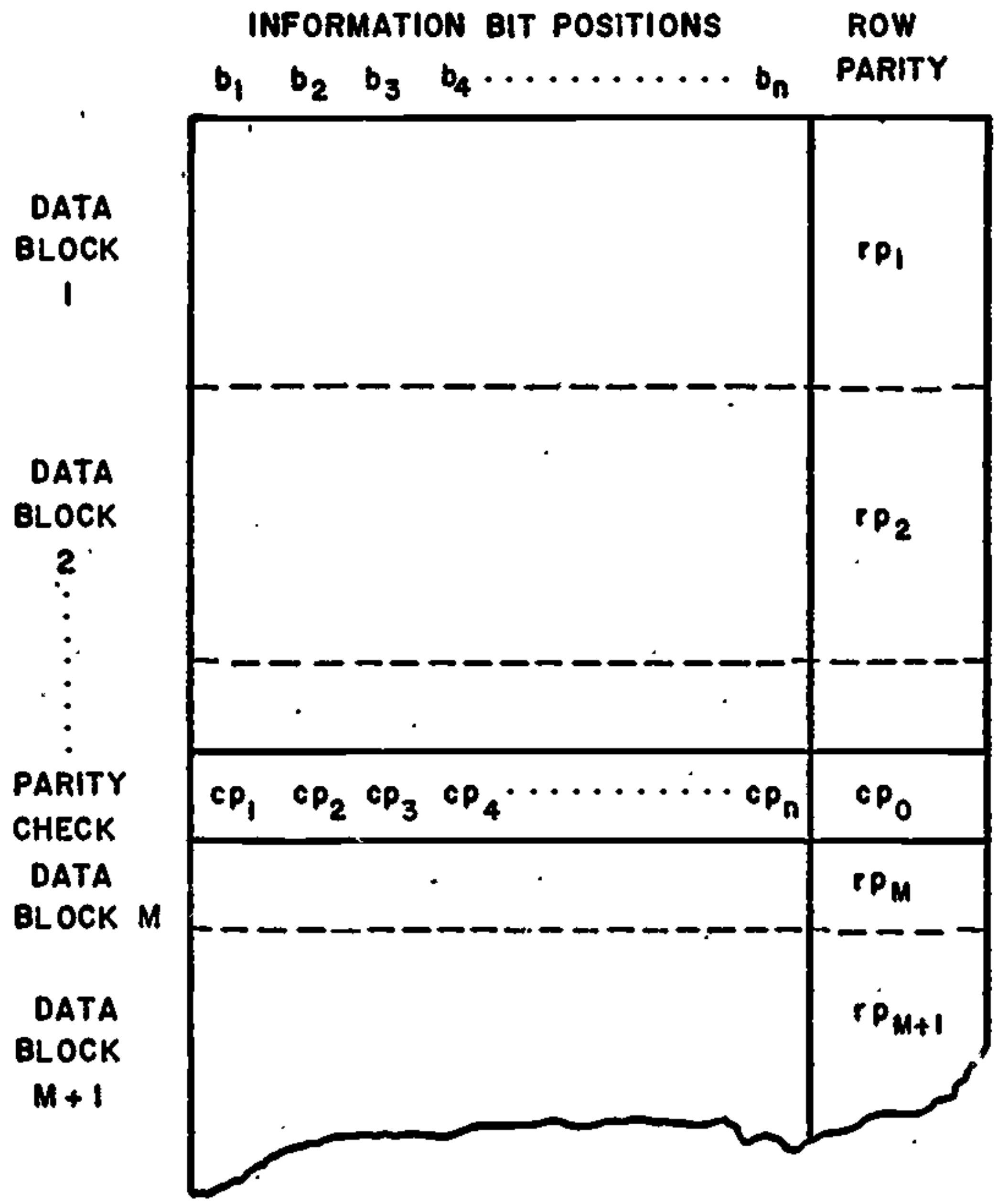
Detection/Retransmission as well as FEC error control procedures involve the transmission of extra or redundant bits which the receiver employs to check for errors in the information bits. With detection/retransmission procedures, the redundant bits only serve as a reference for errors. If an error is sensed, a request is made for the sending terminal to transmit the message portion discovered to be in error. This is why sometimes the detection/retransmission techniques are also referred as Automatic Requests for Repetition (ARQ) technique. With FEC, however, the redundant bits take part in the real-time detection and correction of errors at the receiving terminal; no feedback signalling or retransmissions take place. Although less redundant information and equipment complexity is required for detection/retransmission error control procedures than for the same degree of protection with FEC techniques, FEC permits uninterrupted transmission of a continuous data stream. FEC techniques are specially attractive for data-transmission over propagation paths with large propagation delay (as in the case of geostationary satellite communication with a 0.52 second roundtrip delay). Regardless of which scheme is employed, some errors will ultimately evade the detection process. An error detection system that catches all of the errors in the received bit-stream becomes extremely expensive. Most of the error control systems currently in use raise the level of undetected errors from one bit in 10^3 or 10^4 to one bit in 10^7 or 10^8. One particular device on the market gives an undetected error rate of one bit in 10^{14}, but that is expensive.[70] An error-detection rate of one bit in 10^{14} is much lower than what is needed for most practical purposes. As Martin[70] points out, if one had transmitted nonstop at that rate over a voice line at 2400 bits/second speed, for a normal working week (no vacations) since the time of Christ, one would probably not have had an error yet!

Detection/retransmission procedures generally involve partitioning or blocking the bits into groups--either on a character by character basis or on the basis of group of characters or "word"; the redundant bits in a given block relate only to the information bits of the same block of characters. If an error in a received block (a character or a word) is detected, an automatic request for repetition (ARQ) is generated at the receiving station output and transmitted back to the data source over a reverse channel. In the simplest type of ARQ-control encoded message, blocks are sent one at a time, making a decision to repeat the transmission whenever errors are detected. However, particularly in communications systems involving extremely long paths where round trip delays are appreciable and where simple block-by-block detection/repeat decision procedures make information transmission rather inefficient, such as in the case of AUTODIN system, feedback type error control systems have been implemented using continuous block transmission. This method requires that response from the first data block transmitted be received during the transmission of the second data block; transmission of the second data block does not have to wait the arrival of the ARQ message of the first block. Block 1 would be immediately followed by block 2.

During the block 2 transmission the transmitter would expect to receive an indication from the receiver as to the received quality of block 1. However, this technique requires very large data blocks. For example, with a 100,000 mile transmission circuit (transmitter to receiver and receiver to the transmitter), a transmission rate of 4800 bits/second, and seven-bit USASCII coding, each data block would have to consist of approximately 300 characters.[74] It should be recognized that in a continuous block transmission system, the interconnecting communication facilities must be full-duplex as compared with half-duplex line that would be required with block-by-block detection/retransmission or FEC procedure.

Block codes generally transform a group of k information bits from the data source into a larger group of n bits by inserting (n-k) redundant bits into that block. The redundant bits, (n-k) extra bits check only the information bits in the block. In the more complex convolutional codes[75], the (n-k) extra bits check positions in more than one preceding block. Almost any degree of protection against errors can be obtained by making n sufficiently larger than k. However, a price in terms of equipment complexity and cost is paid for large (n-k). Often the efficiency of error-detection coding techniques is overestimated owing to insufficient appreciation between the characteristics of the code and those of the signalling channel itself. One must consider the increase in modulation rate due to the redundancy of an error-detection-code; increased modulation rate causes an increase in element error rate due to reduction in normalized signal/noise ratio[76], with increasing (n-k), the current interleaving and convolution techniques recoup smaller proportions of the disadvantage, particularly in operation with poor quality channels.

Almost all the important block codes used for error detection and correction are parity check codes. The redundant bits are determined by computation using modulo-2 arithmetic, in which only two results of an addition or subtraction are possible, regardless of the number of bits being added. Modulo-2 arithmetic obeys all the rules of standard arithmetic with a few exceptions and there is never any carrying. The rules for modulo-2 arithmetic necessary for binary codes are: 0 + 0 = 1; 1 + 0 = 1; 0 + 1 = 1; 1 + 1 = 0. In general for modulo-2 additions, an odd number of ones sums to one, while an even number of ones sums to zero. Each parity bit in a code word is formed by taking the simple modulo-2 sum of various information bit positions in the code word. One-dimensional parity check codes are in widespread use in current remote-terminal operation. In these instances, each data block usually corresponds to one character which is checked by its own parity bit. If the bits of each character are assumed to be vertically positioned, then the parity check is known as a vertical redundancy check (VRC). For horizontally oriented arrangements, the same one-dimensional scheme is known as a horizontal redundancy check. The horizontal and vertical array of bits can be visualized by ordering the characters into rows and bit positions into columns (see Figure 2). ASI recommendation for checking on standard seven-bit ASCII code is to use combined vertical and horizontal parity checks described above. M, the number of data blocks used for two-dimensional parity implementation or the length of the block, is variable



GENERALIZED SCHEME OF TWO-DIMENSIONAL PARITY CHECKS
(rp = ROW PARITY, cp = COLUMN PARITY)

Figure 2.

depending on the application, and the seven information bits of each data block (row) correspond to one USASCII character.

The level of redundancy needed to implement two-dimensional parity checks in USASCII is fairly high. If x characters are sent, the ratio of check bits (n-k) to data bits (k) is

$$\frac{x + 8}{7x}$$

Thus for a 20-character message, one-fifth as many check bits as data bits are needed. A very long message needs about one-seventh.

Two other types of block coding techniques are frequently used for error-detection. One is based on the so-called polynomial or cyclic type of codes[70] which is slightly complex to implement but gives a higher ratio of data bits to check bits for the same error performance than two-dimensional parity check codes. The other type is M-out-of-N, or constant ratio codes, where each transmitted character is encoded to always contain the same number of zeros and ones. Transmission errors will be detected as long as off-setting error patterns, in which a one is switched to a zero and a zero is switched to a one, do not occur.

In Forward Error Correction (FEC) techniques a sufficient amount of redundancy is incorporated into a code to allow for automatic correction as well as detection at the receiver. No feedback signalling from the receiver to the data transmitter is required. For example, two-dimensional parity checks are capable of detecting and correcting errors within any row or column having a single erroneous bit. There is a very close relationship between a code's capability for detecting errors and correcting them. In FEC links, it is the power of correction that is primary. The advantages are that with FEC a continuous data stream may be readily accommodated without the need for a reverse channel. The tradeoff disadvantages are closely related to the increased equipment and coding complexity needed to achieve a given error rate, and to time delays associated with FEC shift registers. From the viewpoint of communication efficiency, the continuous block transmission capability is very advantageous from the viewpoint of channels involving extremely large propagation times such as those encountered in geostationary satellite operations. Shift register delays add to one way propagation delay (0.28 seconds approximately for one-way--earth station-satellite-earth station) but the total delay in a well designed correction device would be smaller than those encountered in feedback type error correction systems where the next block of characters could only be transmitted after a positive or negative acknowledgement is received from the receiver, i.e., for a satellite based operation, at least 0.52 seconds after the last bit of the previous block was transmitted. Feedback type error correction systems involving continuous block transmission, with large character blocks, provide an interesting option but are not compatible with situations where an individual interactive terminal converses with the computer in a character-by-character mode; in certain situations, outputs of a number of terminals could be multiplexed together and then transmitted.*†

Convolutional codes are generally preferred for FEC applications. In convolution encoding, information bits are fed directly out to the communication channel and are continuously interleaved with outputs from a parity check generator which performs certain binary additions upon the most recently received k information bits. The rules for the specific arithmetical operations depend upon the code being implemented. Convolutional codes are non-block codes, the length depends on the capacity of the shift register stages that are usually hardwired into the decoder. The total number of bits in this sequence used as the basis for parity computation is also referred to as constraint length of the code. The convolutional codes can be operated at half rate where $n = 2k$, thus giving a new check bit for each information bit to be fed out of the encoder. The non-block structure of convolutional codes make them easier to decode than structured block codes; block synchronization and framing are not required. Information bits and parity bits are always transmitted over the communication channel in an interleaved manner.

Detailed discussions on error correcting codes, convolutional codes in particular, could be found elsewhere.[75,77,78,79] Here it would suffice to say that two basic types of decoding are most widely employed for convolutional codes--threshold decoding and sequential decoding. Threshold decoding is a simpler concept which works effectively with short codes where it is necessary to correct a few errors. Sequential decoding is more powerful but requires more complex circuitary since longer constraint lengths are generally used and successive decoding decisions are highly interdependent.

---

*One must recognize that in remote interactive computing, a reponse time exceeding 1.5-2.0 seconds is usually annoying to the user. The response time, as observed by the remote user, is the sum of the two-way propagation delays (0.56 seconds in case of satellite based operation), delays due to information encoding and decoding, and the actual response time of the computer. The larger are contributions of propagation and coding delays to the response time, the computer has to be oversized to compensate by providing quicker responses.

†Communications satellites are capable of providing high-grade transmission circuits with error rates between 10^{-10} and 10^{-12}--circuits that are virtually error free. The problem lies in the existing ground facilities that provide access to the earth-terminals; most of these terrestrial circuits have considerably higher error rates (1 in 10^3 or 10^4) than that of the satellite circuit. With satellite access based on existing dial or switched facilities, the high-quality or low error-rate of the satellite circuit is purely of academic importance as the overall circuit reliability can not exceed the reliability of the lowest quality component in the circuit. If the existing facilities are bypassed, either using the forthcoming special purpose, commercial digital facilities that promise low error rates of the order of 1 in 10^{10}, or, by locating small earth-terminals in the proximity of the computer and the remote terminals, there is no need to use elaborate error detection and/or correction equipment.