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Memorandum MAC-M-355

RECOMMENDATIONS FOR AN INTER-COMPUTER COMMUNICATION NETWORK FOR M.I.T.

by

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July 21, 1967

Introduction

Remote terminal connections to the time-shared computer systems at M.I.T. have largely been restricted to teletypewriters operating at 100 - 150 bits per second. A number of groups already have or are acquiring sophisticated terminals incorporating small general-purpose computers, and have expressed a need for wide-band inter-computer communication links. This memorandum presents our view on the nature of the computer-communications network required, including bandwidth considerations, requirements for switching, hardware possibilities, and the message format and protocol for data communication. Our specific recommendation is that satellite computer links use serial transmission at standard common-carrier transmission rates in the range 40.8 - 230.4 kilobits per second.

Satellite Computers for Remote Dynamic Displays and Real Time Applications

For several years now a dynamic display (the ESL Console) has been a part of the Project MAC facilities. This console is a general-purpose graphic I/O terminal with multiple input devices and is controlled by a fixed executive program in the 7094 capable of buffering display data and performing a limited set of real time functions connected with the display operation. The facility has been widely used by a large variety of users from many disciplines. This past year a duplicate ESL Console was placed in operation on the 7094 at the Computation Center, but its usage has been somewhat restricted because of time allocation problems at the Center.

A pressing need has been felt for providing the M.I.T. community with multiple stations of this sort located remote from the computer so as to be within easy access of the users, and with less demand on the time and resources of the central machine. When considering how to provide these remote dynamic displays, the most promising approach found was to buffer the display from a small general-purpose (satellite) computer and link this to the multi-access time-shared computer via a communication channel.[1]

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[1] A PDP-7 computer was acquired by Project MAC in 1966 for experiments in buffering the ESL Console, and a workable system is now coming into operation. This system, however, uses a direct data channel connection to the 7094. This direct channel (a parallel one) though capable of high speeds, is expensive and limits the distance to which it can communicate to about 300 feet.

The approach of using satellite computers connected to multi-access computers (MAC, Computation Center) to maintain dynamic displays has several advantages

1. It allows real time response to the user without requiring a special priority system within the time-sharing system.

2. It reduces the load on the central time-shared computer in terms of memory required and machine-cycles used to service the display.

3. It removes any restrictions on distance between the display and the time-shared computer.

4. It also allows the satellite computer and display system to be used off-line as a useful laboratory tool.

We envision a number of these satellite computers (remote display units) at M.I.T. when Multics and the 360/67 become available next year. It is also clear that satellite computers will be installed for other real-time applications such as simulation, connection with real-time experiments, etc., and for remote entry of batch processing jobs. Table 1 is a list of small computers that will be at M.I.T. by January, 1968. Most of these are planned for ultimate connection to the larger time-sharing systems. We therefore feel it important to establish the data format, communications protocol, and the physical nature of the communications link that will connect the satellite computers to the central machines so that the necessary facilities can be provided in time, and that non-compatible installations can be avoided.

A Common Standard for Computer Networks

It is highly desirable to adopt a common data communications standard for both Project MAC and the M.I.T. Computation Center so that a satellite station could operate from either machine. Furthermore an appropriate common standard would provide a means for the Project MAC Computer (GE 645) to communicate directly to the Computation Center computer (IBM System 360/67). It is, of course, desirable that such standards be extendable beyond the confines of M.I.T. Already a group of ARPA contractors (including Project MAC) are considering a communication network

Table 1

Small Computers at M.I.T. by January, 1968

Computer	Display	Organization	Location
1. PDP-7	ESL Console (Kludge)	ESL/MAC	Tech. Sq.
2. PDP-7	DEC 340	ERC	Bldg. 20
3. PDP-9	(In Development)	ESL	Bldg. 35
4. PDP-9	(In Development)	RLE (Stevens)	Bldg. 26
5. PDP-9		RLE (Troxel)	Bldg. 20
6. PDP-6	DEC 340	AI/MAC	Tech. Sq.
7. IBM 360 Mod. 40	2250	CE	Bldg. 1
8. PDP-1	Type 30	EE	Bldg. 26
9. PDP-9		Inst. Lab. (Sutro)	268 Albany St.

linking their machines to form a network of computing machines, and are considering accepting the message format and communication protocol which we have proposed for Project MAC in Memorandum MAC-M-351. Such communication-computer networks of course are the first steps towards the computer and information utilities of the future.

Bandwidth Considerations

The most immediate application for satellite computers in the M.I.T. network will be as controllers for sophisticated display consoles. In this environment, the time-shared computer files are the principal repository for both programs and data for the satellite. The satellite itself normally will have a limited memory capacity (e.g., 200,000 bits) for economic reasons. Typically, the data transmitted back and forth will be new display files, new programs and pieces of data structure. Messages will range from very short ones (one or two computer words) to moderately long ones (a typical display file might contain 30,000 bits). It seems very unlikely that messages containing one million bits would ever be generated in display applications, since the entire satellite memory would normally not be that large.

The end user in this application is the human being sitting at the display console. He is the one who will sense the slowness of interaction if the channel bandwidth is too low. In many cases it will limit or determine what he can accomplish at the display. By the same token since he cannot accept information any faster than his mind and senses can operate, he gains very little by having bandwidth above a certain point, considering the higher cost of obtaining this increased bandwidth.

The cost of bandwidth is spread between the cables, the modems (or data sets) and the interface (or data adapters) equipment at the computers. Both the GE 645 and the IBM System 360/67 offer standard communication line interfaces that cover the range of bandwidth from 1200 bits per second (bps) to 230.4K bps. These interfaces follow uniform standards and are made to match identically to data services offered commercially by the Bell System and Western Union, and to equipment manufactured by a large number of companies in the data communication's field (Rixon, Lenkurt, Collins, etc.). Speeds beyond 230.4K bps require special interface equipment at each machine. Table 2 lists the various communication data adapters available on the GE 645 and the IBM System 360 and their approximate costs. The FCC tariffs for Bell System and Western Union data sets and services are given in Table 3.

From our experience, 1200 bps is too low a bandwidth for an effective dynamic interaction with a satellite computer and display.[1] For instance, it takes 40 seconds to get a typical display file across such a link. It seems to us poor economy to tie up $80,000 worth of equipment (satellite computer and display) waiting for information to come at such a slow rate. The chief attraction for these lower bandwidth (1250 - 2400 bps) links is that they can be provided using standard telephone wires and relatively inexpensive commercially available modems (data sets).

On the other end of the spectrum we see little requirement for providing a user his display file in 1/100th of a second, which would be the time

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1 Two satellite computers operate with CTSS over a 1200 bps line; the PDP-6 of the Artificial Intelligence Group and the PDP-7/340 of the Science Teaching Center.

Table 2

Communication Adapter Options

System	Adapter Unit	Speed Bits/second	Type	Monthly Cost/channel	Remarks
GE645/Multics	CAA 600	1200-1800	Serial Asynch.	$ 142	6 channels available 3 in each GIOC (CAA 600 and CSA 600)
"	CSA 600	2400	Serial Synch.	149	
"	WSA 600	40,800 230,400	Serial Synch.	450*	4 channels available 2 in each GIOC
"	CSE 031	9,000,000	Parallel	2,300	
"	ICPA	80,000		Not avail.	
"	DCPA	3,200,000		Not avail.	
IBM 360/67	IBM Terminal Type III	1200-2400	Asynch. Synch.	129	A maximum of 4 adapter units including all types with each 2701, only two of which can be SDA's
"	SDA-I	2,400	Synch.	206	2 lines operated one at a time
"	SDA-II	40,000 230,000	Synch.	Not avail.	

* WSA not designed yet. These are estimated values.

Table 3

Data Set Options and Tariffs

Data Set Unit		Type	Speed baud (bits/sec)	Comments	Cost/ Terminal Month	Instal-lation Charges	Line charges on private leased line/mile month
Bell System	201A	Synch.	2,000	Dial network/pvt. line 2 or 4 wire	$ 70	$100	$ 3
	201B	"	2,400	Private line-2 or 4 wire	70	100	3
	202C	Asynch.	1,200	Dial network/pvt. line 2 or 4 wire	40	50	
	202D	Asynch.	1,800	Private line 2 or 4 wire	40	50	
	301B	"	40,800	12-voice circuits Private line	250	200	15
	303B	"	19,200	Private line 6-voice circuits	425	300	25
	303C	"	50,000	Private line 12-voice circuits	430	300	25
	303D	"	230,400	Private line 60-voice circuits	450	300	45
Western Union	2 kc	Asynch.	1,200	4-wire service full-duplex throughout on Western Union Broad-band exchange	42	25	
	4 kc	" (Voice Grade)	2,400		57	25	

Tariffs from Massachusetts to California

Bell System - Direct Distance Dialing network for voice-grade service.
WATS unlimited service - $2300/mo.
WATS measured time - $610/mo. for 1st 15 hrs. $34 ea. additional hr.
Voice-grade leased line - $4800/mo.

Western Union - Broad-band Exchange
2 kc $0.65 first minute $0.065 ea. additional 0.1 min. If charges exceed $300 40 percent discount o[illegible]ess.

4 kc $0.75 first minute $0.075 ea. additional 0.1 min. If charges exceed $400 - 40 percent discount on excess.

required on a 4-megabit line. (In addition to requiring an expensive channel at the time-shared computer, special interfacing equipment and more expensive data sets are required.) The user will usually not be getting response from the time-shared computer faster than one or two seconds. If he must wait this long to get the computer's attention, it would seem reasonable that he could wait as much as another second for his data to be sent.

A data rate of 50Kbps would allow a transfer of a typical display file in less than a second. An 8K PDP-9 could be loaded entirely in just over three seconds at this speed. If 230.4Kbps were used, a full core transfer would take under a second. Hence it is our feeling that the best choice of bandwidth for interaction with dynamic displays is 40.8Kbps, 50.0Kbps or 230.4Kbps (standard offerings of Bell System). Standard communication adapters and interfaces for these are offered on the GE 645 and the IBM System 360. This will also permit us to communicate outside the M.I T. campus to anywhere in the country over standard commercially available services.

Our argument for bandwidth requirements here has been predicated on a display application. We expect that a number of other real-time applications will develop using satellite computers interfaced to the same network. It is much more difficult to predict the bandwidth requirements for these new applications. Therefore we should not restrict ourselves now, only to find later that much higher data rates would be needed for a particular application. Hence it may be desirable to lay cables capable of much greater bandwidth than is indicated by our present needs.

Communications Equipment

The New England Telephone and Telegraph Company has offered to look into the requirements for M.I.T. and set up a wide-band system to suit these requirements. The phone company proposal is an off-campus system that will consist of a fully integrated electronic switching system to accommodate both voice and data requirements utilizing voice grade circuits (installation 1972), and a wide-band communication system that will accommodate high-speed information transfer, video and special applications. The Institute is looking into this proposed scheme.

Although it is possible for M.I.T. to employ the phone company to establish and manage the hardware for a wide-band network, the economics of the situation sugg t a possible alternative approach. The cost for 40.8 Kbps service between two points carries an interstate tariff of approximately $250 per terminal month plus mileage charges. We have been informed that a system within M.I.T. will cost about half the interstate tariff. Table 4 lists charges quoted for an intra-M.I.T. link for the wide-band facilities. Part of the reason for the high cost of this service is that the data sets are designed to operate between any two points in the country over a wide variety of types of telephone plants and grades of lines. In the toll trunks, the data stream is transmitted over a channel group or a super-group carrier facility designed for transmission of several voice-frequency circuits. Thus special measures have to be taken to insure some degree of noise immunity, and scramblers are necessary in the data modems to distribute the information more evenly across the band of the carrier.

Table 4

Rates and Charges for Intra-M.I.T. Wideband Services*

Service	Non-recurring Charge	Monthly Rate
One synchronous two-way channel at 40.8 Kbps	$500.00	$260.00
One synchronous two-way channel at 50 Kbps	$500.00	$260.00
One synchronous two-way channel at 230.4 Kbps	$500.00	$265.00

These are order-of-magnitude rates and charges quoted by the New England Telephone and Telegraph Company on July 19, 1967, and are furnished on an interim basis prior to effective tariff coverage. These are subject to change when the tariffs become effective.

In our environment for data communications within M.I.T., the distances involved are hort (two miles or less). Thus it is reasonable to dedicate cables ther by guaranteeing extremely low noise. Further, there is no need for scramblers as dedicated coaxial cables would avoid any crosstalk problems between different wires and channels (there being only one channel per cable). In fact, it appears entirely reasonable to use simple base-band (i.e., d-c) transmission. For these reasons we believe M.I.T. could build and maintain its own network (cables and data sets) much more economically than renting the same service from the phone company. Whether M.I.T. should do this, however, is another question. It is of interest to note that Graybar sells the identical data set (301-B) that Bell uses for their 40.8 Kbps service ($250 per terminal/month) for $2739 to government contractors only.

If M.I.T. decides to pursue its own network, it must concern itself with laying cables to connect the various stations. There presently exists an empty duct under Main and Vassar Streets for cables from Project MAC to the main campus. This duct ends at a manhole cover near Building 20, and has been set aside by Project MAC for "wide-band" cables. Some of the new buildings are being provided with internal ducts during construction.

The wide-band services include both high-speed data requirements and educational television requirements of the Institute. We are at present concerned only with the data transmission, however.

Figure 1 illustrates a proposed configuration for a computer network within M.I.T. which we feel would best fulfill the Institute's future wide-band data transmission requirements. It shows a central switching office for the wide-band links, although it is not clear at this time as to how the ' nks should be switched. The location of this switching center should preferably be in reasonable proximity to the final locations for the IBM System 360 and the Project MAC Computer. The location of this wide-band center, the characteristics of the cables and the nature of the switching equipment should be decided on the basis of M.I.T's overall needs rather than just on Project MAC's immediate requirements.

However, we feel that Project MAC should not be held up in meeting its users' needs until all the details of M.I.T.'s long-range plans are

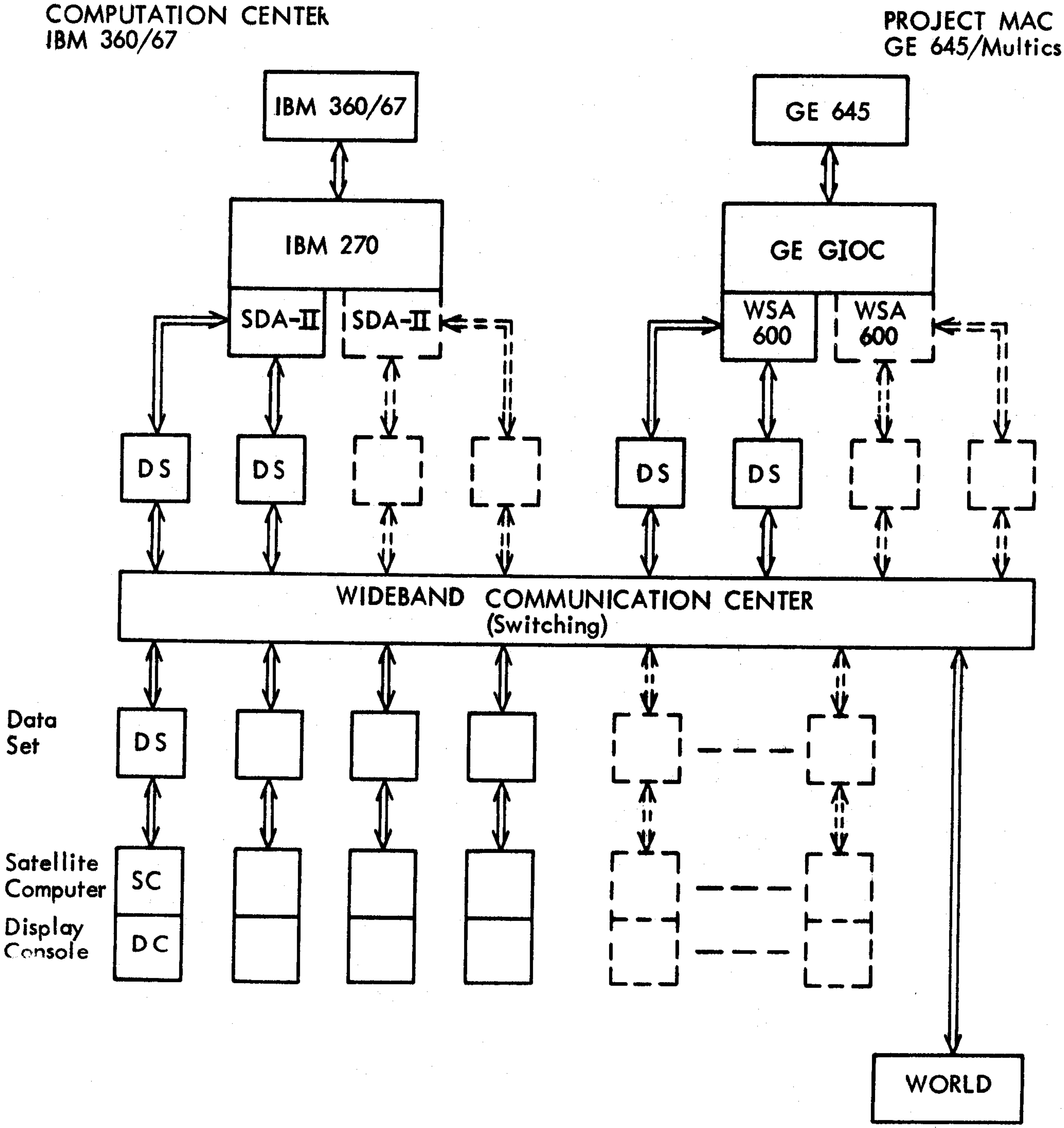

FIG. 1 PLAN FOR WIDEBAND COMMUNICATIONS WITHIN MIT

settled. Therefore we suggest that Project MAC be free to install simple point-to-point conne tions (using either present phone company offerings, or special cables la by M.I.T.) for the present, with an understanding that these will eventually run through a switching center and fit into the long-range pattern. The links may be brought to a common point (preferably a room in some centrally located building), so that switching is possible at a later date.

Other Considerations

The user must make several other choices besides the speed of operation he wishes to use. For example, he must choose between full-duplex and half-duplex operation, between synchronous and asynchronous operation, and between point-to-point and dial switching operation.

Full duplex means the ability to transmit simultaneously in both directions, while half duplex means the ability to transmit in both directions, but not simultaneously. Though full-duplex operation is more efficient and flexible, a large price must be paid for it in that it requires two communication adapter channels at each computer and two circuits for each link. Half-duplex operation should be adequate for most applications.

Synchronous transmission means that characters (and bits) are transmitted at a fixed rate. Asynchronous transmission means the interval of time between characters can vary arbitrarily, although bits within a character are sent at a fixed rate. At higher speeds of operation (50-230 Kbps), the I/O terminals of the computer have only synchronous adapters. At the lower speeds (1200 - 1800 bps) both synchronous and asynchronous options are available. Synchronous transmission is more efficient as it obviates need for start and stop bits with each character, but in turn it requires equipment to synchronize on each bit and character, which results in more expensive terminals.

We, at Project MAC, anticipate the growth of a switched network for wide-band data, though initial operation will probably be point-to-point for the 50 to 230 Kbps speed range. In either case the differences would only be in the link establishment procedures and dial units and no other significant change would be needed in either the data format or terminal equipment.

Data Format and Protocol

The general communication format and protocol procedures proposed for computer-to-computer communications are described in "Message Format and Protocol for Inter-computer Communication," published as memorandum MAC-M-351. This paper does not include the specific recommendations on the satellite computer network for Project MAC, but it is planned to issue such as soon as the details of the computer software system interfaces are available and a network configuration is chosen. The format will follow the ASCII recommendations and include means for transmitting binary information. We feel that this format should be adopted for the entire M.I.T. network. (It should be understood that adopting a standard does not preclude non-standard cases for peculiar requirements.)

System Software Requirements

At present no system software exists to handle the message formats and protocol needs for inter-computer communication for the network we are planning for MAC, and virtually no effort is being expended in this direction. The GIOC interface module (GIM) is being developed to suit all I/O devices but the various Device Interface Modules (DIMs) have yet to be developed. The DIMs should provide for uniformity, error recovery, code conversion and message formatting. We have no information at all on system software in the Computation Center's Model 67.

A joint effort by the users in various disciplines and the Multics System Programmers is required to write the DIMs to suit everyone's needs and requirements. Similar effort by M.I.T. Computation Center System Programmers would be required to develop system software that will make communication possible between the network users and the Computation Center's IBM System 360/67. We strongly urge a joint effort so that the GE645/Multics System at Project MAC and the IBM System 360/67 at the Computation Center can form parts of a single unified network within M.I.T.