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SUMMARY

The functions and structure of the network management subsystem of the GAMMA-NET, a local computer network at the University of Tsukuba, is presented. The network management subsystem is an integrated subsystem that offers a convenient man-machine interface for the network users during the execution of required jobs, and levels the work load throughout the system, as well as manages the network operations.

Keywords: local computer networks, network management, network operating systems

1. Introduction

Computer networks have reached the status of efficient operating utilities as described by Deitel[1]. The significance of local area computer networks is particularly emphasized by Clark, Pogran and Reed[2].

The Science Information Processing Center of the University of Tsukuba has been developing the GAMMA-NET[7,8]---an in-house computer network which connects several large- and medium-scale computers by a high-speed optical-fiber ring bus.

One of the outstanding features of the GAMMA-NET is the role of the network management subsystem NMS as the nucleus of the network operating system NOS, which loosely couples all the operating systems of autonomous hosts together utilizing interprocess communication facilities. Our motive for constructing a loosely coupled system is to reduce the degree of centralization of supervisory control so that the reliability, availability and serviceability (RAS) of the network should not be degraded by the existence of the NOS.

In long-haul computer networks, such as the ARPA network, there generally may be three kinds of network centers: a network information center[3], network measurement center[4], and network control center[5], or network diagnostic center. The principal task of the network information center is to tell users what resources are available to them. The network measurement center monitors the traffic on the network and facilitates evaluation of network performance. The network control center discovers whether a line is operational or not, tests whether it can be put back into operation, presents the information to the network operators, and maintains a general log and display of the state of the network.

In local area networks, these functions are also required. The NMS of the GAMMA-NET is introduced to perform these functions efficiently. The objectives of the NMS include offering a convenient man-machine interface to execute required jobs and leveling the load on the network, as well as managing network operation.

The characteristics of our network management are its fault-tolerant structure using higher-level application protocol, flexibility and expandability so that system administrators can add new service functions independently of existing service functions, integrity such that much of the important information for managing the network can be gathered in one place, and efficiency through a high-speed communication facility.

In this paper, we focus our attention on the functions and structure of the NMS of the GAMMA-NET. Section 2 briefly describes the GAMMA-NET. Section 3, the main subject of this paper, discusses network management strategies, the structure of the network managament subsystem and network management protocol. A data base for network management and an information retrieval tool are also described in this section. In Section 4, examples of network services are shown. In Section

5, the effectiveness of the NMS is discussed.

2. Overview of the GAMMA-NET

The GAMMA-NET is a local computer network which connects several heterogeneous large- and medium-scale computers by a dual high-speed optical-fiber ring bus.

2.1 Hardware structure

The GAMMA-NET consists of the ring bus subsystem RBS and several functional subsystems. The ring bus subsystem includes dual high-speed optical lines currently in operation with a speed of 32 M bit/s, pairs of an optical repeater REP and a ring bus processor RBP which handles the communication protocol at the data link level by firmware, and the ring bus supervisor RBSV which maintains bus synchronization and supervises ring bus system operation. The basic structure of the RBS is a slotted ring with its transmission frame divided into nine subchannels. The data transmission is performed by a synchronous, or rendezvous, transfer method. The functional subsystems are general-purpose computers, each of which is specially tuned to interactive processing for the faculty course (Melcom-Cosmo 800 III-2CPU, 8 MByte main storage, 3 MIPS), to interactive processing for the freshmen's programming course and CAI (Melcom-Cosmo 700 III, 4 MByte main storage, 1.5 MIPS), to batch processing (FACOM M200-2CPU, 12 MByte main storage, 23 MIPS), to administrative data processing (FACOM M160, 6 MByte main sor torage, 0.74 MIPS), or to network management processing (Melcom 70/150, 0.8 MByte main storage, 0.6 MIPS). Since various processing capabilities are required they are heterogeneous and are designed for efficient function-oriented operations with fast response and high throughput. A terminal interface processor TIP is also a subsystem (Melcom 70/40), through which remote job entry devices in addition to remote terminals and graphic terminals can be connected. Every device in the TIP can utilize the network resources and get services in the GAMMA-NET through the ring bus.

2.2 Protocol layers

The GAMMA-NET is intended to provide efficient communication between subsystems. Therefore, it has been required to design and implement efficient protocols with low overhead and high throughput. Much effort has been made for this purpose. The communication protocol of the GAMMA-NET is specified by four hierarchical protocol layers --- the data link control layer, network control layer, function control layer, and application layer --- as shown in Fig.1.

2.2.1 Data link control layer

The data link control layer DL offers services for connection and disconnection of the data link and for message transfer by the synchronization mechanism. The data link control protocol DLP is defined on this layer to specify the DL service functions. The DLP is executed by firmware in the RBP to accomplish high throughput. Details of the design and implementation of this layer are given elsewhere[7].

2.2.2 Network control layer

The network control layer NL manages the logical link between communicating processes in different hosts. The network control protocol NCP is defined to specify the NL service functions. The NCP supports two transmission modes: multiplex mode and burst mode. The multiplex mode transmission is used for relatively short data communication, such as TSS conversation, and the burst mode transmission is used for bulk data transfer, such as file transfers.

2.2.3 Function control layer

The function control layer FL offers an access method interface for system and application programmers. Two kinds of protocols are defined on this layer: interprocess communication protocol ICP and file access protocol FAP. The ICP is prepared for standardizing the logical link as an access method interface for efficient interprocess communication. The FAP is provided to access virtual files in a remote host. This access method is general and powerful, and can be applied to almost all types of files, devices and processes. When a local user process accesses a remote file, a logical link is established first between a remote file server process and the user process. Interactive negotiations between two communication processes verify file access properties, such as system type, organization, attributes and access authentication of the file, before the file server opens and reads and/or writes files on a disk.

2.2.4 Application layer

The application layer AL offers higher-level functions which support application system activities. Several application protocols are prepared for facilitating specific functions on this layer. They include the TSS protocol, the RJE protocol, the network management protocol NMP and the file transfer protocol FTP. These protocols are supported by the FAP or the ICP.

The TSS protocol is prepared for acquiring TSS services provided by TSS hosts from remote terminals. It defines a standard code set, control characters and terminal control sequences.

The RJE protocol is prepared for remote batch job entry, and offers standard procedures for job entry, job status display, job execution, output control and other service functions from a remote job entry terminal.

The NMP is prepared for offering network management services to network users. This protocol is discussed in Section 3 in depth.

The FTP is prepared for transferring files between hosts and to manipulate files in remote hosts. Terminal users can utilize the FTP service functions by appropriate terminal commands in each host.

3. NMS: Network Management Subsystem

3.1 Network management strategies

If a network user wants to utilize some resources in a large-scale computer network, he must generally know where the resources are located in the network and whether he is permitted to use them.

There are several strategies for managing the information about the resources within the network. We discuss here the strategies that are generally employed, and then discuss the strategy employed in the GAMMA-NET. In the following discussion we focus our attention on the relation between the network user, who wants to utilize the resources, and the host where the resources reside.

3.1.1 General strategies for network management

The strategies of network management can be classified into three general types: decentralized management, centralized management and multiple-copy management.

In decentralized management, all of the hosts in the network run independently of each other without keeping a common data base of information about the network. Information about the resources in each host may or may not be maintained in the host. In the latter case, the network user must have enough information about the network to utilize the network services effectively and efficiently; otherwise he cannot accomplish his objectives satisfactorily. Even in the former case, he must continue to connect to and disconnect from hosts in turn, searching for the information on the requested resources until he can get the required information.

This approach, however, has several advantages. First, system crash of a host has little influence on other hosts, although the resources of the failed host become unavailable. Second, each host can give the information on its own resources in the local form used by that host. These information-supplying systems may be realized even in minicomputer operating systems. Third, this approach is very easy and cheap to implement.

In centralized management, all of the information about the network is gathered into a specific host. This host may be a dedicated processor or a general-purpose computer. Information gathering is performed periodically or whenever information changes in a host or hosts. The information-managing host maintains and keeps track of a data base containing the resource information. The terminal user first connects to the information-managing host and requests information on the resources that he needs. When he finds the information that satisfies him, he next connects to the host in which the resources he wants to use are located. This strategy has two strong points: network resources are efficiently utilized and a network user can obtain the information on the network easily and uniformly.

However, this approach has a few drawbacks. First, any of the information in the network must take a uniform format; each host must convert its local information format to a standardized format. Converting all of the information to the standardized format will result in considerable overhead for the network. Second, voluminous data must be transferred between the information-managing host and all of the other hosts to keep track of the data base. This overhead will also be considerable.

In multiple-copy management, a data base containing all of the information concerning the network is kept in every host within the network. When some changes of information occur in a host, the host should notify all of the other hosts of the changes throughout the network. Merits of this approach are: every network user is able to get all of the information about the network from the host to which he is connected. Thus, the RAS of the network is very high. However, the overhead to unify the information format in the network is considerable, just as in a centralized approach. Moreover, the overhead to keep track of the data base in every host is also high. Therefore, it is likely that system performance will be degraded by these overheads. This strategy would not be practical if many hosts are interconnected in a network.

3.1.2 Network management strategy of the GAMMA-NET

In the GAMMA-NET, a compromise strategy is employed. We divided the network information on the GAMMA-NET into three classes: primary, secondary and local information. The classification among them is not absolute. Information that is very important to manage the network, that is frequently used by many users, and that is needed promptly when required is included in the primary class. Information that is not so important or infrequently used compared with the information in the primary class is classified into the secondary class. Information that is not used by general network users and that is locally used by a limited group of users is not included in either the primary or the secondary class.

The strategy of the management is as follows. A data base which contains the primary information is kept in a subsystem, which we call the network management subsystem NMS. Other sorts of information are kept only in each host and are locally maintained by that host. For secondary information, the NMS acts as an intermediary between network users and hosts. The NMS does nothing with local information. Only the local host maintains this information.

A user can query the NMS for the necessary information from a terminal. If the information requested is in the primary class the user can get it directly from the NMS. If information in the secondary class is requested, the NMS acts as the go-between; the NMS request the information from appropriate hosts and returns it to the user.

By this strategy, the GAMMA-NET runs under a centralized management when the NMS is in normal operation, and runs under a decentralized management if the NMS fails. The whole network does not go down even if the NMS fails. Although network users might feel somewhat inconvenienced, the user may access the hosts about which he has knowledge under decentralized management circumstances.

3.2 Design goals of the NMS

The NMS is introduced to offer the following functions:

1) to manage the network common resources efficiently,

2) to guide the network user in the use of the common resources,

3) to level the network load by using information on the network resource utilization,

4) to notify the network user of the current state of each host on request so that he can use the network efficiently,

5) to inform the network user of the system operation schedules,

6) to gather and log information about the error status on the RBS so that the system operators can detect errors of the RBS in early stages and can maintain the RBS easily, and

7) to gather information for system management, such as accounting and documentation.

3.3 NMP: Network Management Protocol

The NMP is provided for offering network management services to network users and for collecting network menagement information. This protocol is an application layer protocol and is supported by the ICP (see Fig.1). The types and functions of the NMP commands are as follows:

(1) attribute command --- to specify the code set used and the maximum permissible size of the receiver's buffer,

(2) request command --- to request information to be sent,

(3) response command --- to respond to a request command,

(4) acknowledgement command --- to acknowledge for requests and responses.

The formats of the NMP commands are shown in Fig.2.

We illustrate the functions of the NMP by explaining the following typical two examples.

The network information request and response scheme between the TIP and the NMS is shown in Fig.3. In this example, a terminal user requests information by a network command "@HELP" to the help process in the NMS through the TIP. (Details are shown in Section 4.) Fig.4 shows the general flow of this interaction. The TIP first connects to the NMS by exchanging the connect request CR and connect confirm CC messages at the NCP level. The attributes are exchanged next. Then, the TIP transfers a request into the NMS and the NMS responds to the request. After the inquiry/response message exchanges the TIP disconnects from the NMS by exchanging the disconnect request DR and disconnect confirm DC messages at the NCP level.

The scheme for information collection from hosts is shown in Fig.5. In this example, the NMS asks a host to send information about the host and the host replies to the request. The flow is : the NMS connects to a host; the NMS and the host exchange attributes; the NMS asks the host to send the information by an NMP request command, and the host sends the information by an NMP response command; the NMS disconnects from the host. This flow is very similar to the flow shown in Fig.4.

3.4 Structure of the NMS

The logical structure of the NMS is an open set of processes which manage network operation or offer a convenient man-machine interface to get services from the network easily and efficiently. Processes which offer new service functions can be added to the set with ease independently of the existing processes.

The main processes in the NMS are the network management process NPR, system-information collecting process SCP and ring-bus-information collecting process RCP. We explain these processes here.

3.4.1 NPR: network management process

The NPR is a table-driven command interpreter which interprets network commands entered by the terminal user and sent by the TIP to this process.

The basic flow of network command processing is as follows: When a terminal user a) logs on to a host, b) logs out from the host, c) switches interaction from the currently connected host to another, or d) requests network information, he always enters one or more network commands. The network commands are accepted whenever the TIP is ready to accept commands. The network command is preceded with an "@" mark. If the TIP recognizes a network command by the "@" mark, it establishes a connection to the NPR in the NMS and then transfers the command text to the NPR. The NRR then interprets the text and links the service routine registered in the command table file CTF (see Fig.6(a)). Service routines invoked by the NPR are independent of each other; new service functions can be added easily in this structure.

3.4.2 SCP: system-information collecting process

The SCP forms a group with the information-supplying process ISP in each of the hosts except the NMS. The SCP periodically requests every remote ISP to send network information about the host in which the ISP is located (see Fig.6(b)). The contents of this information to be collected are described in Section 3.5.

3.4.3 RCP: ring-bus-information collecting process

The RCP requests the RBSV to provide the information on the current states of the ring bus subsystem, such as bypassed, looped-back or normally operational, and of each pair of RBP and host. The NMS is physically connected with the RBSV by a dedicated line. The communications between the NMS and the RBSV are performed by a special protocol.

The RCP also orders the RBSV to start a measurement related to the ring bus communication traffic, to stop the measurement, and to collect the measured data. The data sampled by each RBP is gathered through the RBSV and is stored into a file in the NMS after statistical data processing is performed (see Fig.6(b)). The contents of the information collected by the RCP are described in Section 3.5.

3.5 Contents of the network information data base

The network information that is maintained in the NMS is divided into three sorts: host information, ring bus information and system guidance information.

(1) Host information is the information that is collected by the SCP and ISPs as described in Section 3.4. Three kinds of information are handled at present; other information can be added easily.

i) System information SYS --- the features of hosts, e.g., TSS processing available/unavailable, RJE available/unavailable, operating systems type, CPU speed, main storage capacity, secondary storage capacity, types of special peripheral devices for image and Kanji processing.

ii) Resource information RSC --- the states of hardware resources and software resources available in each host.

iii) Status information STS --- the number of jobs currently in running state, the number of queued jobs, TSS logon counts, I/O request counts, etc. CPU utilization is measured by idle time, system mode time, and user mode time in the current sampling interval time. The status information can be utilized to balance the load on the system.

(2) Ring bus information includes four kinds of information: supervisory information SVI, error logs LOG, console messages and ring bus traffic information TRF. The first three kinds of information are used by system operators to supervise the ring bus and to detect errors of the ring bus. The details of the fault diagnosis, maintenance, and automatic reconfiguration of the GAMMA-NET ring bus,

as well as the details of the cooperation of the NMS and the RBSV, are discussed elsewhere[9]. The ring bus traffic information contains the data measured by each RBP and collected to the NMS. The details of the measurement and the measured data are reported elsewhere.

(3) System guidance information SGI is given by system operators. The NMS allows a terminal user to see system guidance information. The following is included:

available software utilities, such as language processors, application utilities and data bases,

features of hosts,

system documentation,

formats and uses of network commands, and

weekly schedule of network operation.

The HELP process in the NMS is an information retrieval system which is invoked by terminal users. This process handles a data base system that has a tree structure, and the terminal user can retrieve the data base by using the HELP commands.

Fig. 7 shows the structure of the HELP data base and examples of retrieval operations. Fig. 8 shows the formats and uses of the HELP commands.

4. Implementation of Network Services

Here we show some of the implementation details of several network services carried out by the NMS described in Section 3.

(1) Automatic host selection by load leveling policy

Whenever a terminal user wishes to begin TSS processing, he may enter a network command "@SELECT [TSS] [host id]". ("TSS" and "host id" are optional arguments. Every host has a unique host id which is made public to the network users.) In this way he may either select a specific host he wants to use by showing the host id explicitly, or ask the network to select an appropriate host by not specifying any host id. When the TIP receives a command with a host id, it sets up a connection with the host. If it receives a command without a host id, it sets up a connection with the NMS and forwards the command text into the NMS. The SELECT routine in the NMS computes the loading factor by using the data in the system information and status information files, and determines the host that is currently most lightly utilized. Then, the text, "@SELECT TSS host id", is sent back to the TIP and the connection with the NMS is terminated. Since the TIP is informed of the selected host id, it can establish a connection between the host and the user. The algorithm currently adopted to select a host determines the currently "most lightly utilized" host as the host that has the lowest loading factor, calculated by dividing the host's main storage capacity by its TSS logon counts. Fig. 9 shows the detailed flow of the host selection services. Automatic host selection promotes more efficient sharing of network resources and better load balancing.

(2) File directory search assistance

A file-search function is useful for terminal users as a means of searching where their files are located in the network. In the GAMMA-NET, a terminal user can obtain the location and attributes of a file by entering a network command, "@LIST file id". The TIP transfers his file access account implied by his user id and password with the list command to the NMS. The (user id, password) pair, of each active user is registered on the TIP's authentication table. The file access account is unique in the system and common to all of the hosts. After receiving such a command, the NMS makes a connection and sends the command to every host in which each local list program lists the attributes of the objective files. The retrieved attributes and host id are sent back to the TIP via the NMS as shown in Fig. 10. File attributes displayed on the terminal are in local formats.

Another command, "@CATALOG", displays all of the file names which a user has. The control mechanism is similar to that of the list command.

5. Discussion

We discuss the effectiveness of the NMS in this section.

5.1 System guidance service

For the system operators, the NMS is very useful because they only need to input information about the system guidance or system schedule once rather than input the information to each host.

For the network users, the NMS is also useful because they can obtain the information automatically without repeating the actions of connection to and disconnection from each host when they require information widely spread over the network. The NMS relieves much of the user work of entering commands. It takes at least several seconds for a user to enter a command while it takes less than one second for the NMS to connect and transfer the commands.

5.2 Network file services

If a centralized file directory system is incorporated, update or delete operations must be executed in the centralized file directory system when a file is updated or deleted in any local host.

This could cause a bottleneck at the NMS and a system crash through failure of the NMS. The message-switching approach employed in the GAMMA-NET reduces those risks.

If the files in the network are managed in a distributed way, the network user must access each host to obtain information on files. The message-switching approach is very effective for reducing the network user's work at his terminal.

5.3 Structure of network information data base

If any information not included in the primary class is used frequently, the information may be moved into the primary class easily in the GAMMA-NET. Conversely, if any information in the primary class will not be used frequently, this information may be moved into the secondary class. This flexibility will result in better performance.

The status information used primarily for automatic host selection is currently collected every 30 seconds. The data length transferred from each host is 92 Bytes (see Fig. 11). The traffic between the NMS and the hosts is very low and can not cause congestion on the ring bus. The system status changes rather slowly and there is no need to shorten the sampling interval.

6. Conclusion

The structure and implementation of the flexible, fault-tolerant and integral network management subsystem in the GAMMA-NET have been described in this paper.

Although the concept of network management is not a novel one, there was no existing network management system that met our requirements.

In our system, the network user can obtain much of the information on the network even without being aware of the existence of the network management subsystem. The high-speed communication facility allows the network user to feel as if he were searching the help file in the currently connected host.

Several service capabilities are not implemented yet. These will:

provide a uniform accounting procedure throughout the network,

control and maintain the virtual network file system efficiently, and

utilize software resources by name.

Uniform accounting procedure may be realized by the cooperation of two processes, one to collect information from user accounting files in each host and the other to gather the accounting information into the NMS.

The network file system and resource naming problems are now being studied.

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Fig. 1 Structure of hierarchical protocol layers

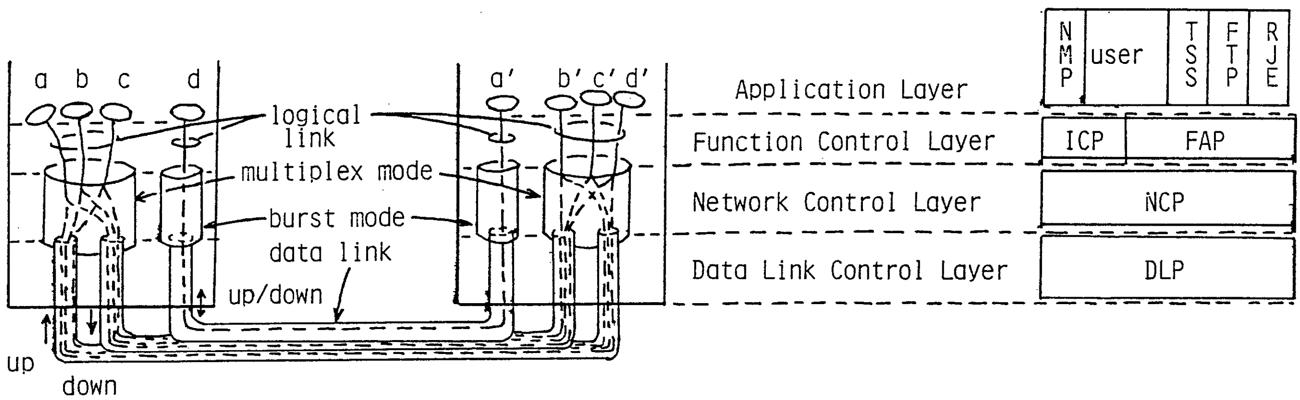


Fig. 2 NMP command formats

	1B	1	1	2
attribute command	type (1)	flag	code	buffsize
request command	type (2)	flag	user data	
response command	type (3)	flag	inf (1)	user data
acknowledgement command	type (4)	flag	inf	

type ··· message type id

flag ··· eod/eof flag

code ··· data code

inf ··· control of transfer

Fig. 3 Network information request/response

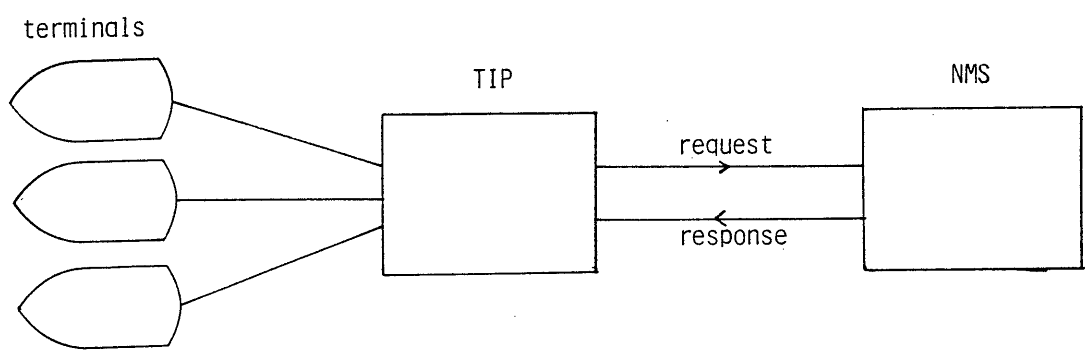


Fig. 5 Information collection from a host

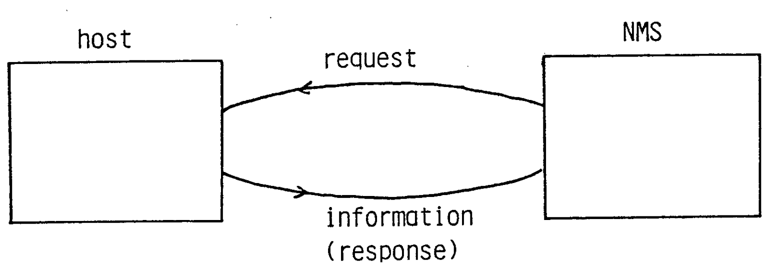
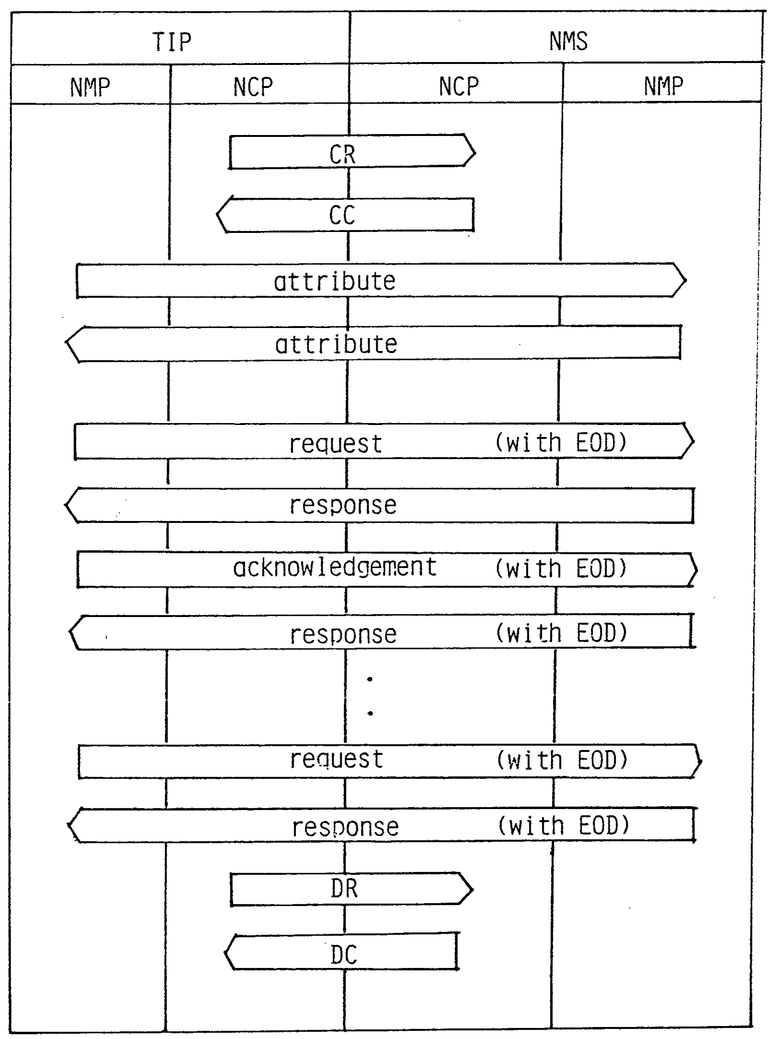


Fig. 4 General flow
of the network information request/response



Note: EOD (end of data)

Fig. 6(a)   Structure of the NMS

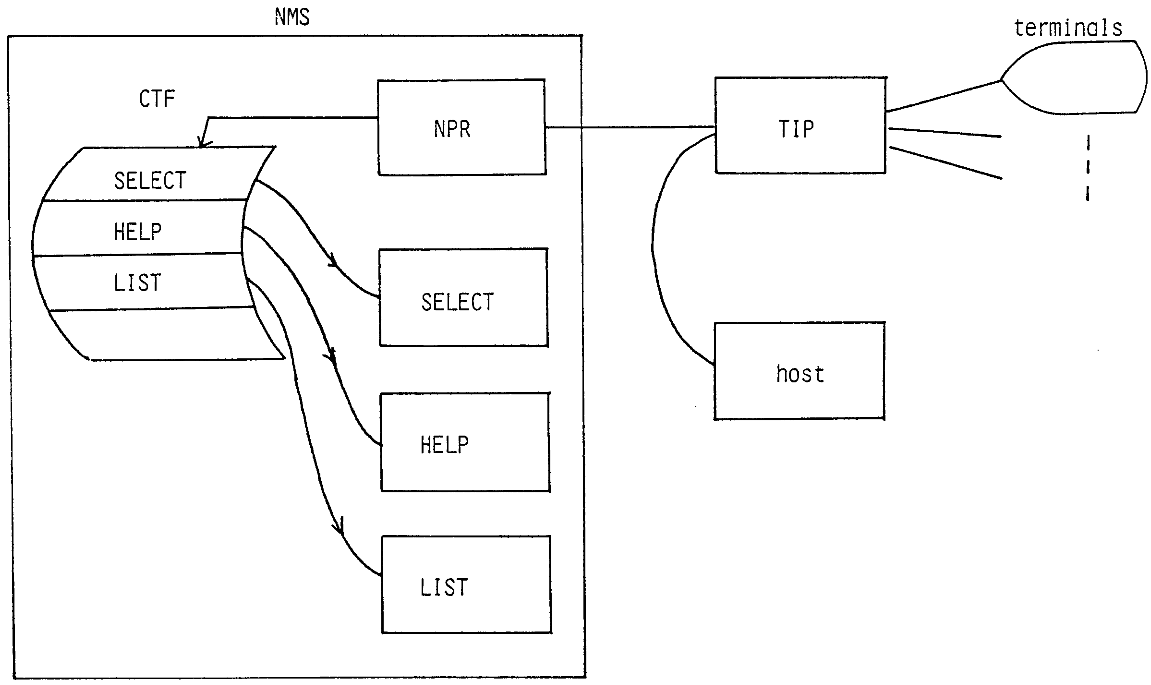


Fig. 6(b)   Structure of the NMS

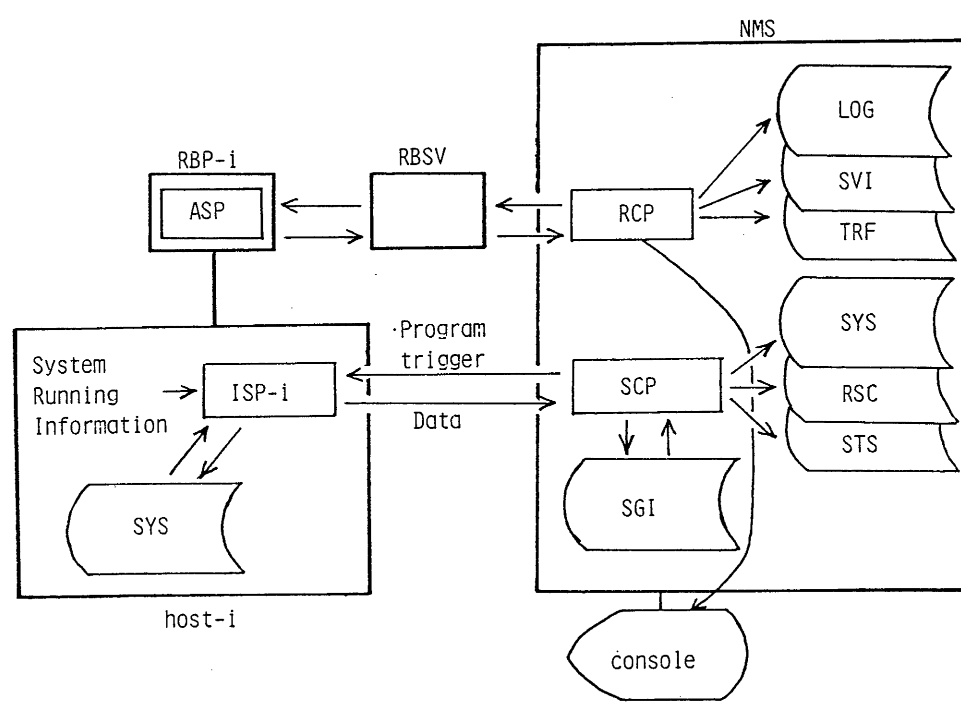
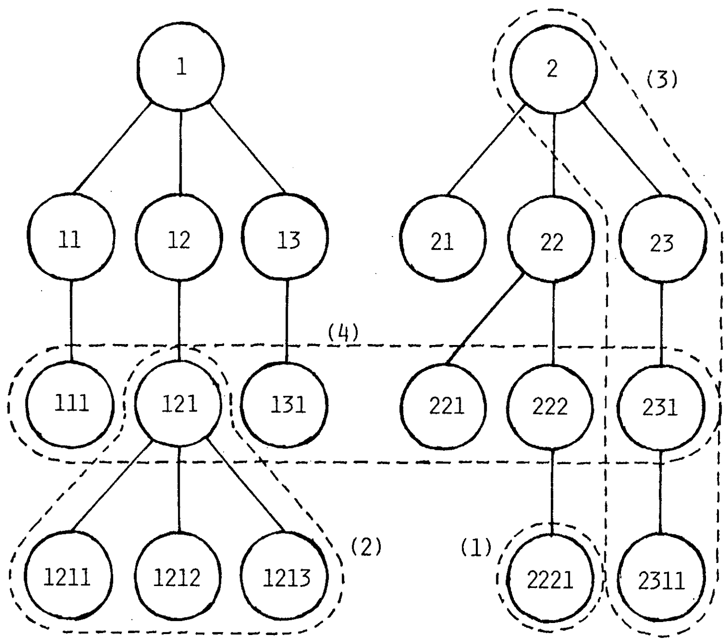


Fig. 7 Structure of the HELP data base and examples of retrieval



(1) Retrieval of a specific node

(2) Retrieval of a specific node and its descendants

(3) Retrieval of a node and its proper ancestors

(4) Retrieval of nodes of the same depth

Fig. 8 Formats and uses of the HELP commands

COMMAND	FUNCTION
HELP	display information
SYMBOL	assign symbolic key to a node
DS	cancel the symbolic key assignment
COUPLE	create link between nodes
DECOUPLE	delete link between nodes
UP	go to an upper level
DOWN	go to an lower level
RIGHT	go right
LEFT	go left
END	end the process
ADD *	add information
DELETE *	delete information
UPDATE *	update information

* These commands are privileged ones.

Fig. 9 Host selection and TSS logon procedure

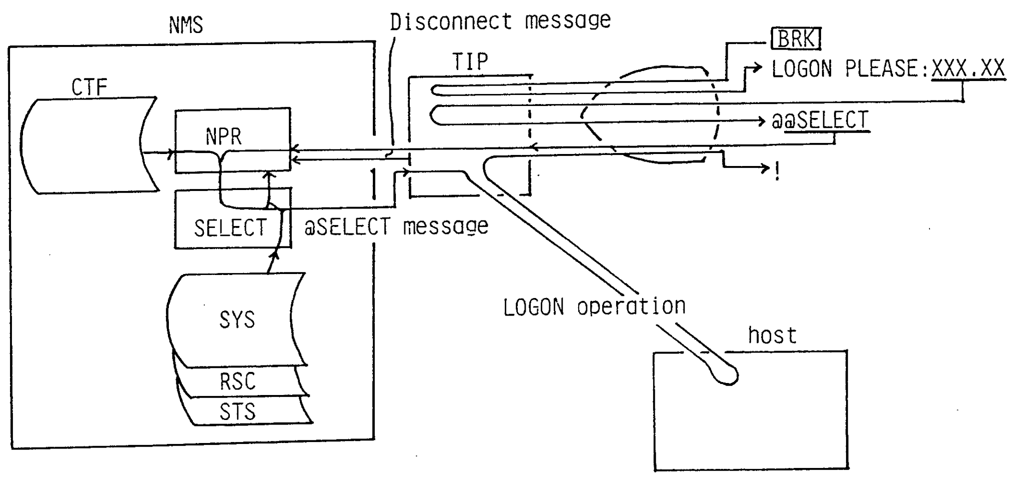


Fig. 10 Automatic file search control

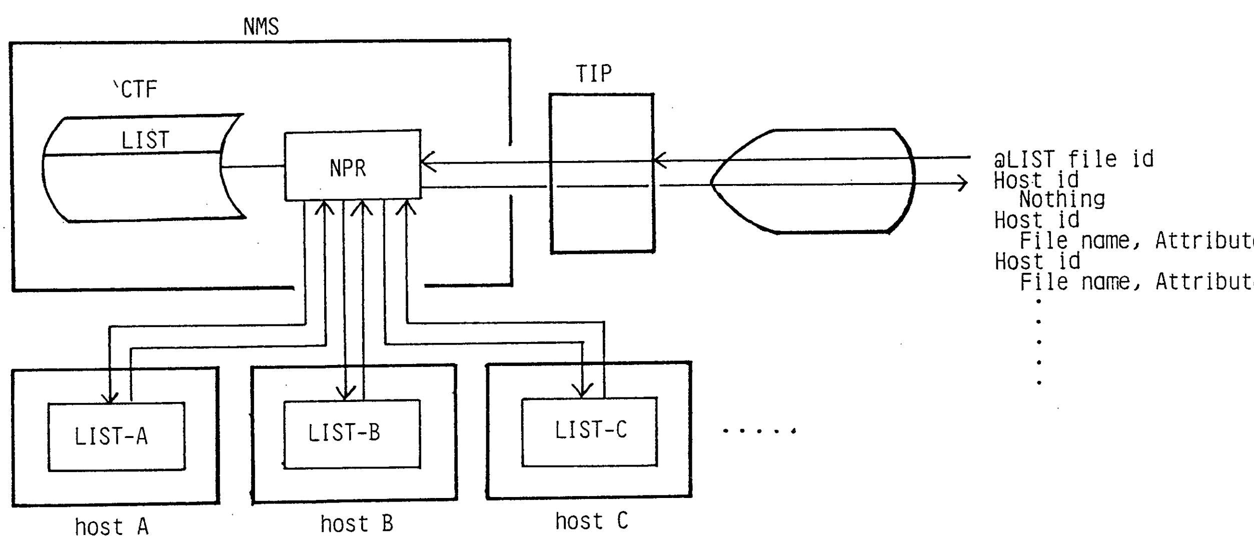


Fig. 11 Format of the Status Information

4	8	8	4	4
inf id	host id	sampling time	number of maximum users	
			batch	TSS

8	8	4	4		
currently used memory size		number of current users			
batch	TSS	batch	TSS	batch	TSS

20			4	4	4	4	4
CPU time			I/O counts	elapsed time	90% response time	input queue length	output queue length
system	idle	total					

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TITLE

NETWORK MANAGEMENT IN A LOCAL COMPUTER NETWORK

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ABSTRACT

The functions and structure of the network management subsystem of the GAMMA-NET, a local computer network at the University of Tsukuba, is presented. The network management subsystem is an integrated subsystem that offers a convenient man-machine interface for the network users during the execution of required jobs, and levels the work load throughout the system, as well as manages the network operations.

SUPPLEMENTARY NOTES