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COMPUTER NETWORKS

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PRIMER OF COMPUTER NETWORKS

ABSTRACT

The definitions, services and basic design philosophies of computer networks will be discussed. The parameters of network will be listed and the expression of average delay time in detail will be investigated. Finally, the hardware and software components will be summarized.

АННОТАЦИЯ

Основы сетей ЭВМ.

Описываются основные понятия, услуги и цель проектирования. Перечисляются характеристики сетей и подробно исследуется определение среднего времени задержки. В заключение представляются элементы программного обеспечения и аппаратных средств в сетях ЭВМ.

KIVONAT

Ismertetjük a számitógépes hálózatok alapfogalmait, szolgáltatásait és tervezési célkitüzéseit. Felsoroljuk a hálózati jellemzőket és részletesen megvizsgáljuk az átlagos késési idő kifejezését. Végül összefoglaljuk a számitógépes hálózatok hardware és software elemeit.

MEASUREMENT OF COMPUTER NETWORKS

ABSTRACT

First the motivation of the network measurement will be discussed, then the results of a traffic investigation and the basic types of monitors will be introduced. A hybrid monitor network and the experiences of ARPA measurements will be studied. Finally, the problems have to be solved will be summarized.

АННОТАЦИЯ

Измерение в сетях

В начале работы описывается цель измерения, в дальнейшем представляются результаты исследования потока данных и основные типы различных мониторов. В дальнейшем проводится ознакомление с гибридной мониторной сетью и опытом, полученным при измерении системы ARPA. В заключение перечисляются задачи, еще требующие решения.

KIVONAT

A mérési célkitüzések ismertetése után egy adatforgalom vizsgálat eredményeit és a különböző monitor alap-tipusokat mutatjuk be. Majd egy hibrid monitor-hálózatot és az ARPA mérési tapasztalatait ismertetjük. Befejezésül összefoglaljuk a megoldásra váró feladatokat.

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PRIMER OF COMPUTER NETWORKS

I. THE COMPUTER NETWORK AND ITS SERVICES

Simultaneously with the extension of the computer networks a question has come to the fore: how can computer centres be made more economical and available for more users. The first approach to the solution of the problem was the development and application of the time-sharing computer system, then on the basis of the experience gained through this, the development of computer networks started. The purpose of this study is to give a survey of the fundamentals of the computer networks.

A computer network is such a system of automatically communicating computers which allows the interactive sharing in the resources. Interactive sharing is to be understood as meaning that any node of the network can access to any resources of the network in such a way as if the resources were a local one. A further assumption is that only a connected system of autonomous and independent computers can be considered as a network. Each computer of the network can, therefore, also operate locally with its own operating system, though it can take part in the network too, directed by a supervisory program of a higher level. Besides the resource sharing network, in a wider sence of the word, such multi-terminal computer system can also be considered as a network the task of which is, primarily, the transmission of data from the terminals to the machine and back /communication network/. The network of the cooperating autonomous systems /distributed network/ can also be enumerated among the computer networks, the former distributing the single steps of the solution of a complex problem among the members of the network.

The services of the computer network can be distributed into two main groups:

- hardware resource sharing,
- software resource sharing.

The sharing in the hardware resources ensures that a particular rarely used hardware system element /e.g. a disk store of 10^9 bits/ is located in only one node of the network. The economic advantages of this are obvious.

The sharing of the software resources can be realized in several

The sharing of the software resources can be realized in several ways:

- If a load levelling is intended, both program and data are sent from a local node to a less loaded, distant one. The program run having finished, the result is returned to the sender. This service is characteristic to the Cybernet [5] and DCS [2].
- In the case of program sharing, data are sent to a distant node whereupon the program in the latter performs the designated operations on the data base. This service is cumbersome on account of the different codes and file conventions.
- Data sharing is generally more economical as here the programs are sent to the node where the large data base exists. In this case the machine-dependent handling of the multi-dimensional blocks and the different source language instructions may cause difficulties.
- The dynamic file access allows access to a distant data group in the same way as if the latter were a local one, i.e. any user of the network can change the file. This service is characteristic, e.g. to the DCS network.
- Remote job initiation is also a useful service as it can control the job steps in the case of data base and program in a remote node.

2. COMPOSITION OF THE COMPUTER NETWORKS

A computer network consists of hosts and node computers and channels connecting the nodes. The node computers are occupied with the control of the connections while the hosts have the resources of the network at their disposal and solve the envisaged tasks.

The nomination of the node computers and hosts is not uniform in the literature. The most well-known names can be found in Table I.

Table I

NETWORK	NAME OF HOSTS	NAME OF NODE COMPUTERS
ARPA	HOST	INTERFACE MESSAGE PROCESSOR /IMP/
IBM NETWORK/440	GRID NODE	COMMUNICATIONS SUBSYSTEM
CYBERNET	CENTROID	NODE
CANUNET	HOST	NODE COMPUTER
MERIT	HOST	COMMUNICATIONS COMPUTER
DCS	PROCESSOR	RING INTERFACE

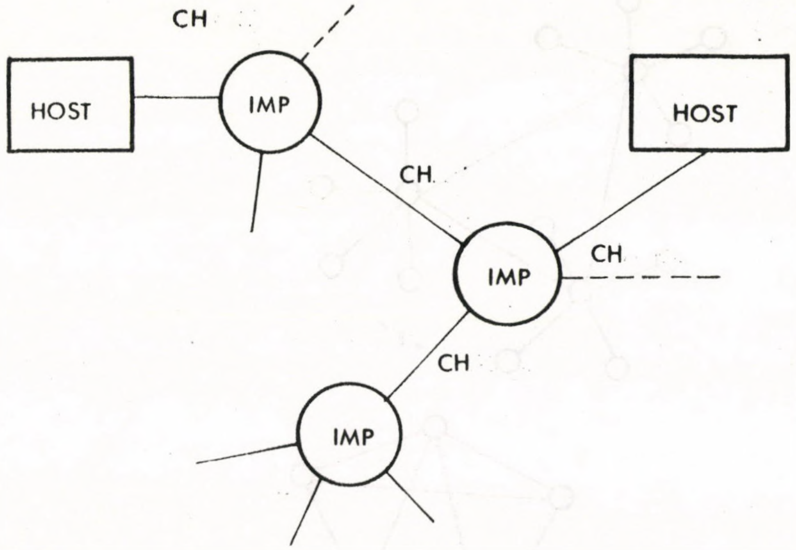

Fig. 1 Typical part of a computer network

Part of a network can be seen in Fig. 1.

The network is homogeneous if the hosts are identical or compatible. If they are different the network is heterogeneous. A typical homogeneous network is, for example, that of the TUCC [11] which consists of IBM 360 and IBM 370 machines. The advantage of the heterogeneous network is the great variety of hardware tools and the easy extensibility. A disadvantage of the network is, however, the laborious sharing in the data and programs as well as the necessity of the data and instruction conversions. A typical heterogeneous network is ARPA [2] the smallest machine of which is a PDP 11 of low capacity while its biggest one is an ILLIAC-IV.

The organization of the network is determined by means of connection between the channels and the nodes. The most frequent connection modes can be seen in Fig. 2. The centralized or star network is shown in Fig. 2a. Its application is advantageous if

- the geographical distances are short
- there are by several orders of magnitude more resources in the central node than another /e.g. LCS/
- the test and control of the network is to be performed centrally /e.g. IBM NETWORK/440/ [1].

In Fig. 2.b a decentralized network can be seen which consists of the interconnection of several centralized networks. Its advantage is that the controlling functions are distributed into several nodes thus the probability of catastrophic failures is smaller.
The distributed network of Fig. 2.c gives a possibility for controlling the network, storing, and forwarding messages in each node. Its advantages are:

- it is more economical than the former
- on account of the failure of one single line no node will fall out as each node can be generally approached via two ways
- if one node becomes defective the other nodes remain approachable.

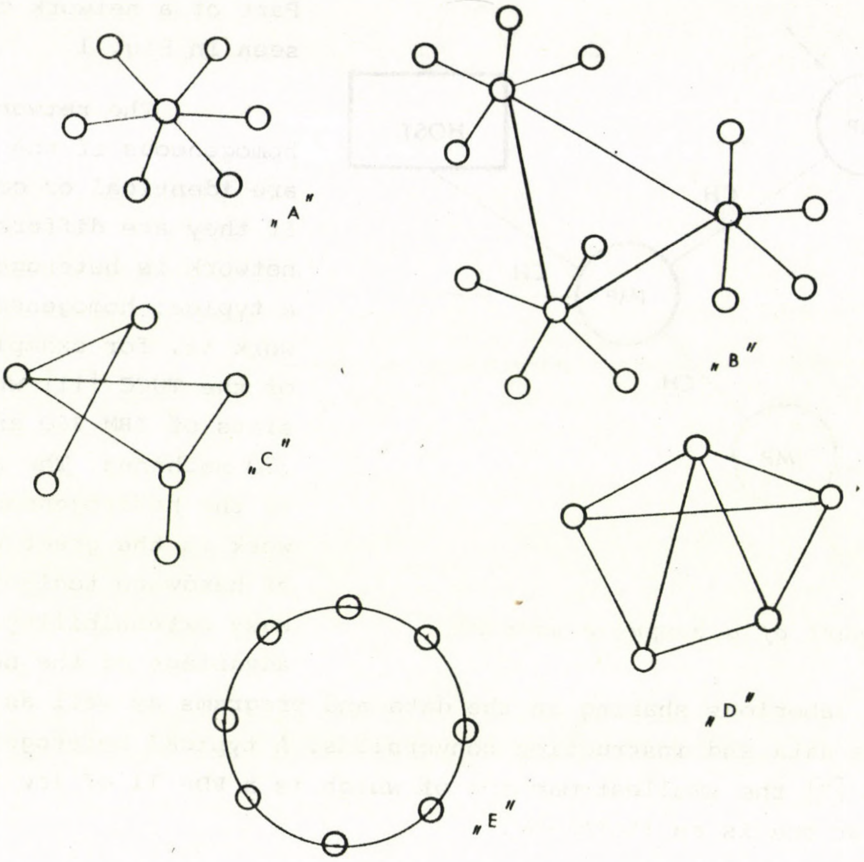

Fig. 2 The most frequent types of computer networks

A typical representation of the distributed networks is the ARPA. A network is called a fully distributed one if every one of its nodes is interconnected /Fig. 2.d/. MERIT [5] and OCTOPUS [6] are such types.
In Fig. 2.e a ring network is shown. The nodes of the network, i.e. the RING INTERFACES are interconnected by a unidirectional communication line. The task of controlling can be carried on either by the RING INTERFACES, or by a single separate unit: the RING CONTROLLER. Its application is particularly advantageous for short geographical distances. The proper choice of synchronization and the prevention of infinite loops arising should, however, be carefully considered. A well-known ring network is, for example, the DISTRIBUTED COMPUTING SYSTEM.

3. DESIGN CONSIDERATIONS

The purpose of the newtwork design is to establish a network for the user that provides all the services enumerated in Chapter 2 and, in addition makes the use of these services, by various means, attractive. What are these means?

- Easy use
- Reliability
- Data transmission with minimum failure
- Short response time
- Extensibility
- Low cost.

The term easy_use is understood to mean that the use of the network resources should not be more difficult for the user than the use of the local ones. It is important that the command language of the network should be easily learned. Users that have recently entered the network have to be assured of the possibility of transparent transmission and that the HELP mode of operation is available.

The reliability of the network is first of all a function of its topology. In addition, it depends on the probability of failures in the single channels and nodes. At least two or more physical connections must exist between each node in order that every node might have access to the other parts of the network should a failure in one path occur.

The data_transmission_with_minimum_failure is important because the failure rate of computers is very much lower than that of the transmission lines. The rate of undetected failures can be diminished by simple odd-even parity check, to $1/10^8$. This means one undetected failure per day in the case of a 1200 Baud transmission speed. Although the data transmission with minimum failure can be realized by the application of error detecting and error correcting codes the designer of the network must not forget that the throughput of the network and the exploitation of the lines decrease on account of the large number of error checking characters and the resultant redundancy. Therefore, the most simple solution, that of automatic-repeat-request, is very often chosen as a means of error correction.

The short_response_time /quick response/ is one of the important parameters from the point of view of the user. The definition of the average delay time can be found in Section 4. The response time contains the delay of the message passing from the source station to the destination and the acknowledgement. It can already be disturbing for the user if the response time is several seconds.

Extensibility refers both to the hardware and to the software system of the network. The basis of the hardware extension is the standard module construction of the network elements; the software extension means: on the elaboration of the system the expectable maximum lay-out should be taken into consideration.

The very existence of any network depends on the costs of establishing and maintaining the network. It is worthwhile for the user to join a network only if it is economically more advantageous than a local system, i.e. it renders more services for less money.

4. NETWORK CHARACTERISTICS

The traffic of messages depends on many factors in the network. These characteristics describe the construction of the network, the structure of the messages, the queueing principles and the rules of routeing. The parameters most frequently used for the characterization of the computer networks are the following:

- average delay time [sec]
- throughput
- reliability
- cost
- location of the nodes
- distribution of the resources
- topology
- channel capacities [bit/sec]
- capacity of the node stores [bit]
- node processing time
- length of message [bit/message]
- routeing technique
- laws of message priority
- techniques of the flow control.

The first four parameters are perhaps the most important ones for the user. The average delay time of the network determines the response time and it is characteristic to each interactive mode of operation that the user is waiting for a quick response. Figure 3 represents the connection between the delay time and the traffic by nodes for two types of routeing, in the case of a network with 12 nodes. In Section 5 the determination of the delay time is separately discussed.

The throughtput is the number of forwarded and processed messages during unit time. In Fig. 4 the cost is shown as a function of the throughput.

Reliability means the probability of whether each connection of the complete network is "living" or not. Instead of the full network reliability the concept of the terminal's reliability is often used. The R_{ij} terminal reliability means the probability that between nodes i and j at least one path, exists. If, for the terminal reliability the nodes are not referred to, then it is always the weakest terminal reliability of the network that should be taken into consideration.

The user generally has to bear the full cost of the network; this comprises the costs of establishing the network, its maintenance, as well as the costs of hardware and software units and the transmission of data.
The allocation of the nodes, the distribution of the resources and the topology can mostly be considered as having already been given in the first phase of the design. The topology can also be affected, to a major extent by reliability considerations and economical points of view.

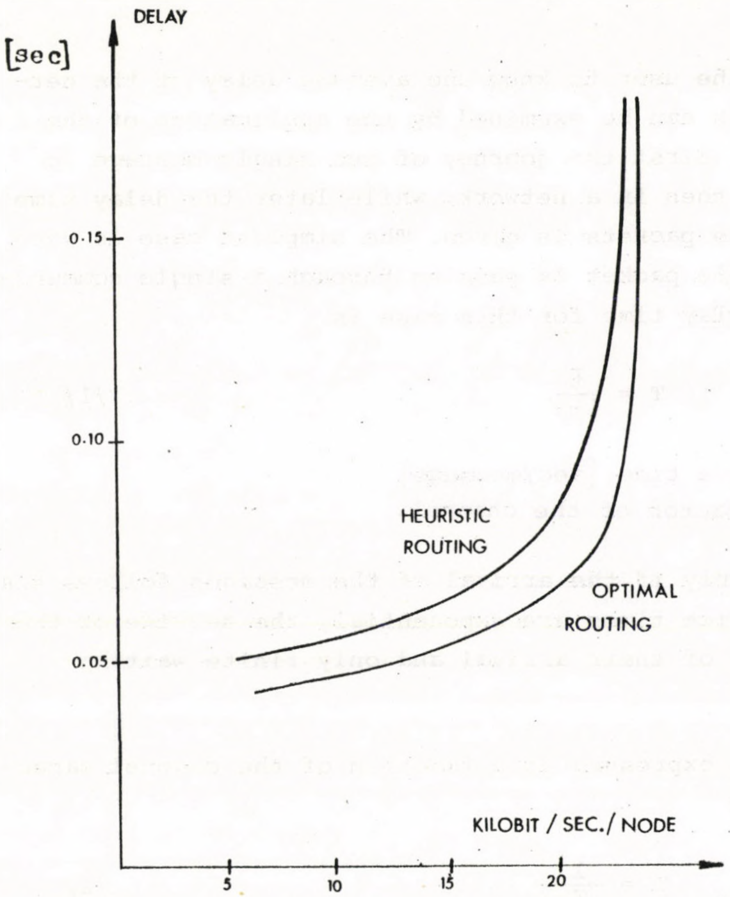

Fig. 3 Traffic of a network of 12 nodes for two routeing techniques

The channel capacity is the number of bits transmitted during the unit time, its connection with the delay time is dealt with in Section 5.

In the case of small traffic the message length and the node processing time are not critical parameters if the node store has a sufficiently big capacity.
It is an interesting task for the designer to choose the proper routeing techniques, to consider the different priority principles, and to set up rules for the flow control.

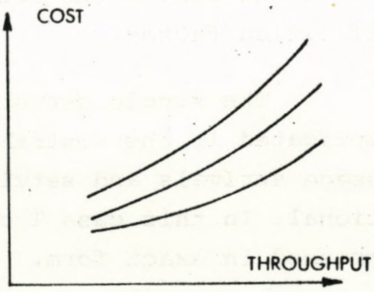

Fig. 4 The cost as a function of the throughput. The parameter is the response time

5. THE AVERAGE DELAY TIME

It is essential for the user to know the average delay of the network. The delay of the messages can be examined by the application of the models of the queueing theory. First the journey of one single message is examined in a single channel, then in a network, while later the delay time of a message consisting of more packets is given. The simplest case is when a message consisting of a single packet is passing through a single communication channel. The average delay time for this case is

$$T = \frac{\bar{t}}{1-\rho} \qquad /1/$$

where $\bar{t}$ is the average service time [sec/message]
ρ is the utilization factor of the channel.

Formula /1/ is true only if the arrival of the messages follows the Poisson distribution, the service times are exponential, the service of the message occurs in the sequence of their arrival and only finite waiting queues can arise.

The delay time can be expressed as a function of the channel capacity and average message length

$$T = \frac{1}{\mu C-\lambda} \qquad /2/$$

where C is the channel capacity [bit/sec]
$\frac{1}{\mu}$ the average message length [bit/message]
λ the Poisson constant [message/sec]

In Fig. 5 the delay time can be seen as a function of the channel utilization factor.

The single server system becomes complicated if the distribution of the message arrivals and service times is optional. In this case T cannot be expressed in exact form.

If not the simplified single server system is examined but a composed network with multiple nodes the determination of the delay time is much more difficult. It can be proved, however, that the message delay arising in the total network is with good approximation proportional with the

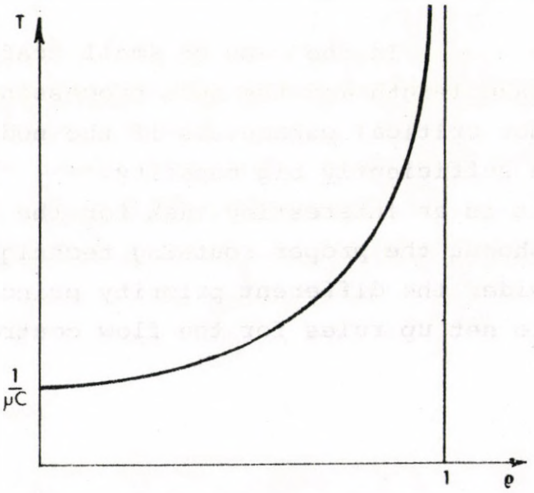

Fig. 5 Delay time as a function of the channel utilization factor

superposition of the delays in the single channels. The proportional factor depends on the traffic and the throughput of the network, i.e. a full average delay of a message

$$T^{*} = \sum_{i} \frac{\lambda_i}{\gamma} T_i \qquad /3/$$

where T_i is the delay of the message in the i-th channel,
λ_i the average message traffic in the i-th channel,
γ the throughput of the network.

Formula /3/ can be more refined taking into consideration the time /K/ spent by message processing and forwarding in the nodes and the propagation delay time $/P_i/$ caused by physical channel. Supposing that node processing time /K/ is, both in each node and also at the destination, the same the modified form of formula /3/ will be

$$T^{*} = K + \sum_{i} \frac{\lambda_i}{\gamma} \left[T_i + P_i + K\right] \qquad /4/$$

where delay T_i is caused by the service and by the queueing before the service. The delay caused by the service depends upon the average message length $\frac{1}{\mu'}$ and means the time necessary for the transmission of a message. Apart from the message itself the queueing delay is caused by the supplementary information which consists of acknowledgements, headers and parity checks. It does in fact mean the very time which is spent by a message in a queue waiting for a free channel.
Thus the delay time in the i-th channel is:

$$T_i = \frac{1}{\mu' C_i} + \frac{\lambda_i / \mu C_i}{\mu C_i - \lambda_i} \qquad /5/$$

As that the message consists of several packets, if the model of Fultz [7] and Cole [3] is used Equ. 4 will be modified as follows:

$$T_{\text{MULTI-PACKET}} = K + \sum_{i=1}^{M} \left[\frac{\lambda_i}{\gamma}\left(\frac{1}{\mu C} + P_i + W_i'\right)\right] + (\bar{m}-1)\left(\frac{1}{\mu C} + \left[\sum_{jk} \frac{\gamma_{jk}}{\gamma} \bar{\tau}_{jk}\right]\right) \qquad /6/$$

where C is the channel capacity supposed as constant
$\bar{m}$ the average number of the packets in a message
γ_{jk} average number of the messages arriving from node j to node k
$\bar{\tau}_{jk}$ average time between the packets arriving from node j to node k
W_i' waiting time of the queue in channel i

The waiting time

$$W'_i = \frac{\lambda'_i/(\mu' C_i)}{\mu' C_i - \lambda'_i} \qquad /7/$$

where λ'_i is the average number of the effective and the supplementary messages in the i-th channel

$1/\mu'$ the average size of the messages if the messages contain the controlling information, too.

For the sake of completeness it should be mentioned that Eqs. /5-6/ can be written with good approximation in another, more easily treated form that can be also better compared with the measurement results of the network [8].

6. HARDWARE AND SOFTWARE ELEMENTS OF THE COMPUTER NETWORKS

The hardware elements of the computer networks comprise many items of computer equipments /terminals, concentrators, front-end processors, etc./. The choice of the hardware elements should conform to the elements employed for remote data processing. The computers applied in the networks have two characteristic types:

- the hosts and
- the node computers.

The hosts may consist of a single computer or of a system from several machines. /There is also such a network definition that considers a terminal as a host./

The node computers is /depending on the design of the network/, either connected to the operating system of the host /e.g. IBM NETWORK/440// or is a fully independent unit which executes the jobs quite independently of the host, /e.g. ARPA/. The five principal tasks of the node machine are:

- serial and parallel conversion, modulation and demodulation
- handling of messages /disassembling into packets and assembling/ and storing
- error checking, acknowledgement, automatic request repetition
- flow control, prevention of blocking and message congestion
- routeing /choosing the most favourable connection/

It should be noted that there are networks /e.g. CYGALE, IIASA/ which render the service of "datagram" where the handling of the messages is the task of the hosts.

The node machines of the network are interconnected by communication channels. Characteristic to the connection are the line mode of operation /simplex, duplex, half-duplex/, the data transmission processes /serial parallel, synchronous, asynchronous, analog, digital/ and maybe the type of multiplexing/ time, frequency, synchronous, asynchronous/. Should each channel pass through the local or district switching exchange a direct physical connection will be built up between two nodes for the duration of the call. This is the circuit-switching communication. In the case of transmitting, many host messages, the delay is unacceptable. The delay is negligible if the traffic consists of rarely arriving, long messages. The establishment of the connection needs a time of about 10-15 secs. In the case of message-switching the connections between the two nodes differ from circuit-switching. The message carries the address of the destination while the intermediate nodes store and forward the message. This type of operation can therefore also be called "store and forward" operation. The typical delay time is in the order of 100-150 msec. It is difficult to choose the capacity of the intermediate stores if the length of the messages may extend from some bits to several thousand characters. This can be avoided by breaking up the messages into packets of fixed length. Such packet construction is characteristic to networks ARPA and CANUNET. Each packet is transmitted in the network independent of the others. The breaking up of the messages into packets and the reassembling of the packets into a message is carried out by the node computer.

The software structure of the computer networks is described by the protocol. The protocol is the summary of agreements referring to the format of the messages and its relative timing. The protocols are generally of several levels. The higher level protocols deal with the communication of the users or the user processes. The lower level protocols specify the mechanism of the communication between the computers and the nodes. The levels of the protocols can well be seen in Fig. 6.

The tasks of the communication interface-communication interface protocol /protocol between the nodes/ are:

- routeing
- flow control
- error check

The tasks of the host-communication interface protocol are:

- forwarding of messages with header and trailer
- distinction and separated handling of several message types /e.g. control or text/

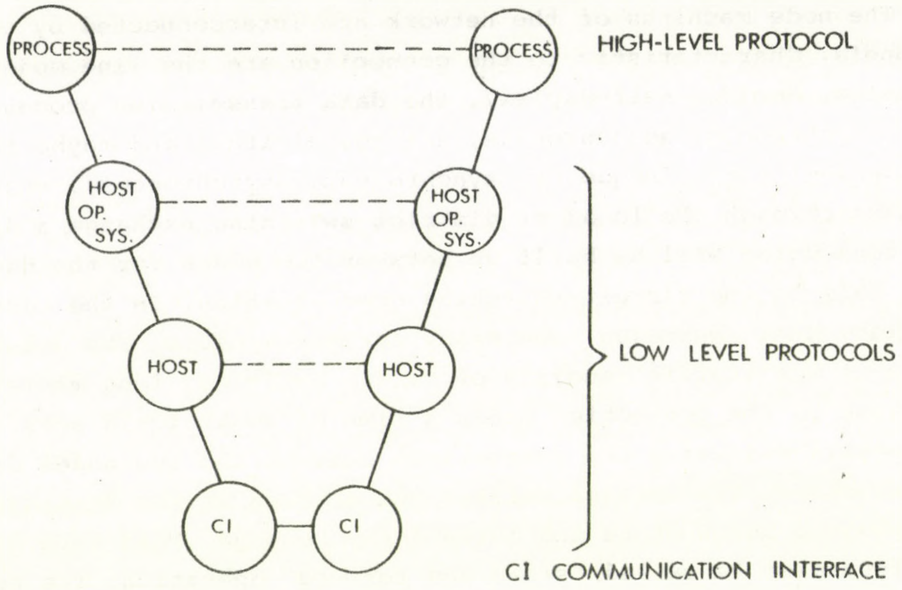

Fig. 6 The levels of the communication protocols

The host-host protocol is responsible for the following:

- to initiate connection
- to maintain the successful connection
- to interrupt it at the end of the message.

The user process-user process protocol is the highest level in the network. It generally establishes the connection between two user processes by ensuring a transparent transmission for every lower level protocol. Note: In Fig. 6 the lowest level protocol determining the transmission through the hardware communication line is not represented.

7. PROBLEMS TO BE SOLVED

In connection with the hardware and software elements of the networks and with the design and analysis of the complete network, many problems are still to be solved [4,10]. Some of the more important of these are enumerated below:

1./ Dynamic network theory

The theoretical examination of the networks is at present based either on static approximation or on simulation. Such theoretical methods are needed which also take the dynamic characteristics of the network /e.g. the alteration of the traffic/ into consideration.

2./ Theory of network protocols

The network protocols are now elaborated rather at random, often without the necessary theoretical basis, often in a hurry. An adequate overall theory, with unambiguous description and comparison of the protocols is needed.

3./ Measurement of the networks

In addition to the many services they can render, networks are able to measure themselves. The evaluation of network measurement made by hybrid monitors or by software monitors and, on the basis of the results, the modification of the network parameters have been performed in several systems [3,8,9]. What is still missing, however, is the examination whether or not the methods of stochastic measuring techniques are applicable to network measurements.

4./ Circuit-switching or packet-switching

The Post Administrations of different countries have an enormous amount of experience in connection with the circuit-switched networks. On the other hand, for message-switched and hybrid /circuit- and message-switched/ networks a large sample of case-studies ought to be made in order to obtain a proper basis for comparison. Recommendation X.25 of CCITT suggests the use of packet-switched systems. Thus if the Post Administrations accept it, this question will be answered.

5./ Message-switching with priorities

Depending upon the type of traffic the response time demands and the characteristics of the data are different, therefore, it is important to examine the message traffic of the networks to determine priorities.

6./ Centralized versus distributed control

7./ Centralized versus distributed data base

8./ Examination of mixed networks /speech and data/

9./ Model of the network users which differs from that of the time-sharing system

10./ Security of the network

11./ Optimization and reliability of the software

12./ Protection of privacy and secrecy of the network

These are very many applications where the last mentioned task is one of the most important problems /e.g. national security/

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MEASUREMENT OF COMPUTER NETWORKS

1. MEASUREMENT CONSIDERATIONS

As an introduction an outline will be given as to what has to be measured in computer systems and networks and why; what kind of monitors are applied and which are the most troublesome sources of failures.

Why is it necessary to measure computer systems and networks? The most important reasons can be arranged in three principal groups:

a./ Control of the operation
  - to determine the load character of the jobs
  - to know how resources will be utilized
  - to control the network traffic

b./ Data collection for network design and theoretical research
  - to ensure adequate statistics for the system model parameters
  - to determine the relationship between the different hardware and software parameters

c./ Error examination
  - to detect the errors using exact methods
  - to diagnose the reason for failures.

The purpose of the measurements is, therefore, to get to know the computer system and network. Since it is impossible to measure each characteristic item of a set of data, at least the most important parameters need to be measured. To decide which these are is rather an arbitrary process. Computer systems are mostly characterized by the following parameters:

- throughput
- response time /turnaround time/
- resource utilization
- job load.

For computer networks the quantities to be measured can be divided into four main groups:

a./ Time measurements
  - time necessary to set up and to disconnect a connection
  - time necessary to transmit a message

- time necessary to recognise and correct an error and initiate the proper operation
- time between the arrival of each messages
- time necessary to disassemble a message into packets and to re-assemble the packets to form a message
- time duration for using the resources
- time duration for occupying the communication channel

b./ Storage capacity measurements

- used up capacity of the main stores in the nodes
- used up capacity of the background stores in the nodes

c./ Event counting

- number of transmitted messages
- number of processed messages
- number of transmitted and processed bits
- number of required services

d./ Measurements of queues

- number of messages in the different waiting queues
- number of packets, characters and bits in the messages
- quantity of data queueing for the main storage systems
- quantity of data queueing for the background storages.

Computer systems and networks are measured by monitors. Three types of monitors are to be found: software, hardware and hybrid monitors. For measurement of the network monitor system, "monitor networks" are used which are separate networks or integral parts of the networks to be measured. The monitor network is generally a centralized network at the hub of which the measurement centre is located. It is important that it should embrace the operation of the measurement data coming from a distance, in both cases by minimal human intervention.

The task of the monitor is also the collection and the arrangement of the measurement results. The forms of arranged representation of the results are the well-known histogram, the system profile, and recently, the Kiviat figure [5]. The first of these three needs no discussion. The system profile generally represents the activity of the system resources in a graphical way /Fig. 1/. It sets the activities to horizontal parallel axes relative to a 100 per cent full system time. The Kiviat figure draws the activities into a unit radius circle on axes corresponding to the resources of the system. By connecting the coherent points a very expressive, stereoscopic-like representation is given. On the left side of Fig. 2 a Kiviat figure corresponding to the 100 per cent activity and full overlap can be seen.

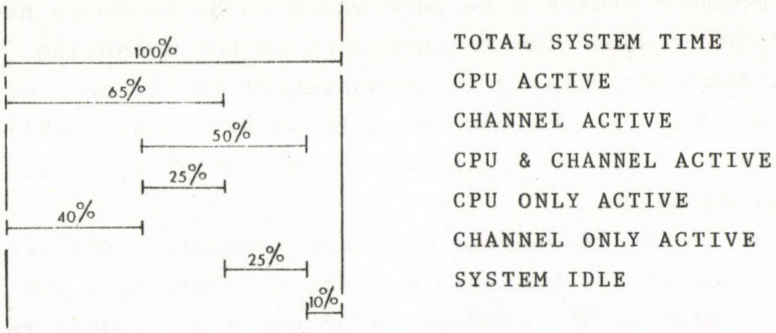

Fig. 1 Characterization of the activity of resources by system profile

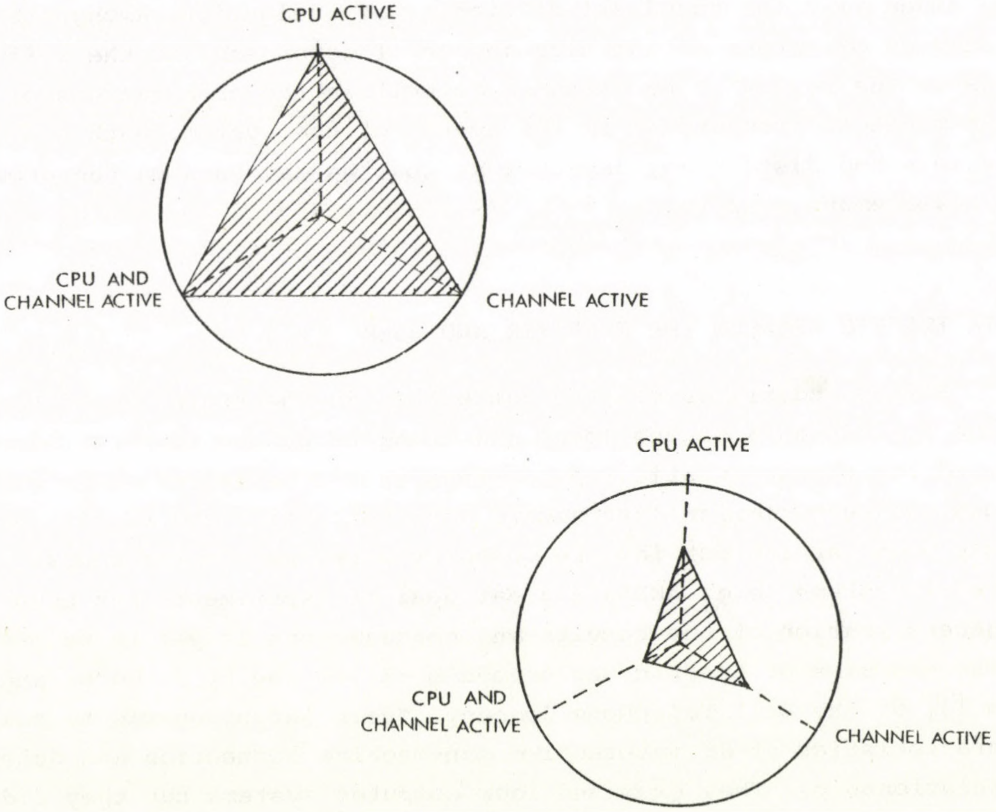

Fig. 2 Kiviat figures

Since during the course of measurement by monitors many types of errors may occur, attention is called especially to two sources of errors. One source is when the measurement disturbes or changes the quantities to be measured. As an example 10 peripheral processors can be connected to the central processor of the CDC 6000 series and one of the former can be used as a hardware monitor. The measurement obtained is correct up to the time that the system is not saturated. In the opposite case the application of

the 10-th processor as monitor causes a failure which is by no means negligible. A further example is where the transmission of the measuring messages of the network does not falsify the measurement in the case of a small amount of traffic while in the case of a large amount of traffic the effective message traffic will be decreased on account of the transmission of the measuring messages.
The other source of error is the resolution of the measurement. The event counting and data collection of the hardware and software monitors are always related to a clock signal. The production of the clock signal is a task of the monitor or the system to be measured. From the point of view of the interpretation of the collected data the resolution of the clock is in any case critical. Should the resolution be too high the monitor does not measure the events between the clock signals. Should it be, on the contrary, too fine, an extraordinarily large quantity of measurement results will be given with the resultant difficulty of evaluation. Among the possible sources of errors is the high degree of dependence of the software monitors on the system to be measured as well as the observations of the hardware monitors independent of the events of the system. Both are disadvantageous and disturb any impressions that we may gain on the grounds of the measurement results.

2. DATA TRAFFIC BETWEEN THE COMPUTER AND USER

Erlang and his associates collected, at the beginning of the twenties, the traffic data of the local and trunk telephone conversations and determined the characteristic regularities of the telephone calls and occupations. No such similar large-scale data collection and traffic measurement have been carried out for the computer networks. In the course of measuring several systems /e.g. ARPA/ a great deal of experiments has been gained but a generalization of the results and consequences is yet to be presented. Among the examples of traffic measurements is the one by E. Fuchs and P. Jackson [3] of the Bell Telephone Company. Their intention was to collect the characteristics of an interactive man-machine connection and determine their relationships. They examined four computer systems but they did not publish any specific data on them for the sake of preserving secrecy. It appears, however, in their study that two of the systems are applied for scientific purposes, one for solving business problems, the fourth one being used principally for interactive application. The job load of each of the four computer systems varies considerably. The model of the data stream can be seen in Fig. 3.

1 CONNECT
2 COMPUTER BURST SEGMENT
3 USER BURST SEGMENT
4 USER INTERBURST TIME
5 COMPUTER INTERBURST TIME
6 DISCONNECT
7 IDLE TIME
8 THINKING TIME
9 USER INTERCHARACTER TIME
10 COMPUTER INTERCHARACTER TIME
11 COMPUTER BURST
12 USER BURST

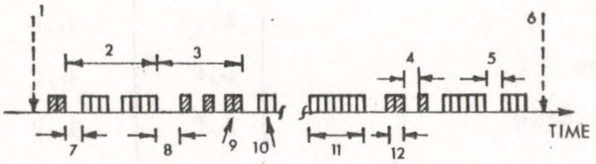

Fig. 3 *Model of the data stream*

In the model the user and computer segments alternate. The segments are composed of bursts and the period between bursts. The burst consists of characters and times between characters. /Note that the time axis consists of discrete time steps necessary for character transmission./ The idle time in the user segment is the think time while during the idle time in the computer segment the computer prepares the user program or the program waits in the queue.*

Also characteristic of the traffic are the number of the user and computer segments during one connection, the number of characters by bursts and the time needed for the transmission of the character.
Fuchs and Jackson collected a great number of data so that they could examine the traffic of the four computer systems. They tried to fit the measured data of the discrete variables to the Poisson, binomial and geometrical distribution while the data of continuous variables to the gamma distribution family. The goodness of the fit tests is examined by a special composed test. The detailed results are given in Table 1. It is interesting that all discrete processes can be characterized by a geometrical distribution except the number of characters in the user burst for system C. The distribution of this can be described by an impulse function which is a degenerated form of the geometrical distribution. The continuous variables can be characterized by gamma distribution while the think time, idle times and the times between the bursts by lognormal distribution.

The goodness of fit tests was acceptable at the 5 per cent level of significance.

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* In the case of the application of buffered terminals the period between the computer bursts is negligible.

Table 1. Distribution of the data stream parameters

Random variable	System			
	A	B	C	D
Number of segments by calls	G	G	G	G,CP
Think time	L,Γ	L,Γ	L,Γ	L,Γ
User interburst time	L,Γ	L,Γ	L,Γ	L,Γ
Computer interburst time	L,Γ	L,Γ	L,Γ	L,Γ
Number of bursts user segments	G	G	G	G
Number of burst/computer segments	G	G	G	G
Number of characters/user bursts	G	G	I	G,CP
Number of characters/computer bursts	G	G	G	G
User intercharacter time	Γ	Γ	Γ	Γ
Computer intercharacter time	Γ	Γ	Γ	Γ

Explanation of terms in Table 1:

G	geometrical
L	lognormal
Γ	gamma
CP	compound Poisson
I	impulse

The analysis of the data traffic clearly proves that the distributions are independent of the examined systems, of the job load of the computers, and of the user tasks. Supposing other systems, other applications and loads, the type of distribution remains unchanged; only the parameters of the distributions are found to be altered.

3. MONITORS

When the requirement of measuring the computer system first arose it was first intended that this task be solved by software monitors. The software monitors are parts of the operating system of the computer to be measured therefore they are greatly dependent on its instruction set and on the structure of its system tables. For this reason a number of types of hardware monitors have been elaborated. Hardware monitors are completely "invisible" to the operating system of the machine to be measured and this is already a disadvantage. In order to eliminate this imperfection hybrid monitors were introduced. The monitors today have an extended literature [8,9] , the bibliography given in Ref. [1] is particularly emphasized.

A possible classification of the software monitors is the following:

- system accounting logs
- interrupt-intercept monitors
- sampling monitors.

Most of the operating systems contain system accounting logs which write the name of the job, the active resources, the entry and release to and from the main memory, the active CPU and I/O time as well as the beginning and the end of the run. This monitor is suitable only for observations of macroscopic character. Its advantage is, however, that it does not disturb the operation of the measured object. For example, the system accounting log work of the real-time operating system of an IBM 360 was examined and it was proved that measurement caused not more than 1 per cent decrease in activity.

The interrupt-intercept monitors analyse the reason for the interruption for each interrupt request and record the state of the system tables. A monitor routine systematizes and processes the results. The advantage of this type is that it forms an integral part of the system to be tested. An important requirement is that the monitor routine should be run by high priority otherwise some monitor processes can be omitted on account of the interruptions of more levels.

The operating system should be modified to the minimum extent in the case of the application of sampling monitors. This type of software monitors requires much CPU time and memory space than the others. The sampling monitor routine has to be written the same way as a user's program in a multiprogramming system. The monitor reads out the contents of the system tables in regular or random time intervals. The disadvantage of this is that the processing of the event occuring during the time intervals between the sampling is missing.

The other large group of monitors is formed by the hardware monitors which are strictly separated both physically and logically from the system to be measured. The general scheme of hardware monitors can be seen in Fig. 4. The electric signal belonging to the events to be observed will be connected to an interface to which an amplifier is also connected. Properly amplified the signal arrives at a combination unit. This circuit produces different combinations of the signals and allows masking, too. The output signals of the combination unit appear at the input of a time-and-count unit. This unit consists of several registers and maybe of a small memory. Its purpose is to count the selected signals or measure their duration.

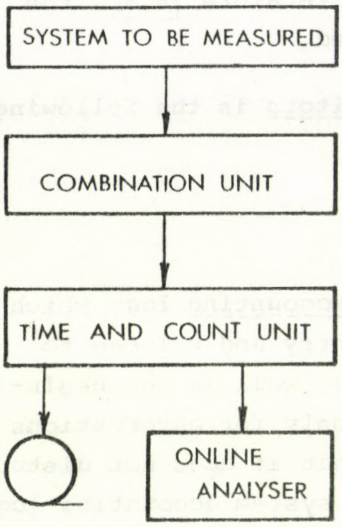


Fig. 4 Hardware monitor

Data collection is performed by the tape unit, evaluation by the on-line analyser. The total system independence of the hardware monitor is disadvantageous since the observation of important events can be left out.

The hybrid monitor is a programmed modification of software and hardware monitors /Fig. 5/. The software monitor remains a part of the operational system but the hardware monitor can also be considered as an intelligent terminal for the system to be measured. The functioning of the hardware monitor is controlled by a small machine which is connected to one of the data channel of the machine to be measured. The presence of the small computer in the monitor ensures a wide application and variability. The small machine can reorganize the funçtions of the combination logic unit by programming and allows versatile on-line data processing. Among the three monitor types the performance of this latter is the highest/the same refers to its price/.

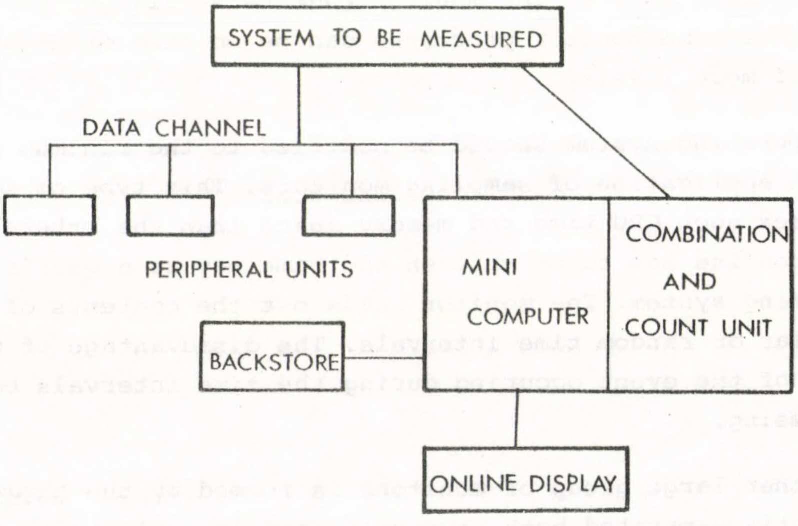
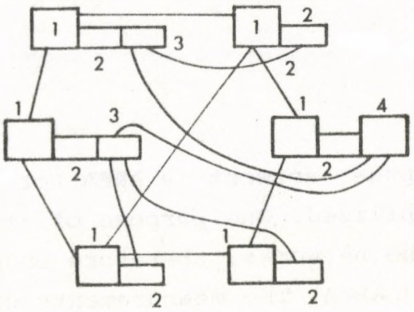


Fig. 5 Hybrid monitor

4. MEASUREMENT OF COMPUTER NETWORK BY A HYBRID MONITOR SYSTEM

Since the measurement of the computer network is rendered more difficult by the fact that the nodes are generally widely dispersed geographically speaking, the activity of the monitor system ought to be distributed along the whole network. Although extremely few network monitoring systems have been developed as yet, the tendency seems to be the distribution of the tasks into two parts. One part of the tasks is concentrated in a measurement center /controlling and coordination of the measurements, analysis of the results/ while the other part of the tasks, the measurements themselves are distributed along the nodes. This type of hybrid monitor system [6,7] has been developed by D. Morgan and W. Banks in one of the Canadian Universities. It was employed in the examination of two small laboratory networks and for the comparison of minicomputers of different types.

The layout of the monitor system can be seen in Fig. 6.



1 NODE WITH MEASUREMENT SOFTWARE

2 REMOTE CONTROLLED HYBRID MONITOR

3 REGIONAL MEASUREMENT CENTRE

4 NETWORK MEASUREMENT CENTRE

Fig. 6 Network measuring monitor system

The measurement software is distributed by the nodes and is in direct connection with the remote controlled hybrid monitor. The hybrid monitors are controlled by the network measurement centre via the regional network measurement centre. The modules of the hybrid monitor are illustrated in Fig. 7. The small machine belonging to the monitor is a PDP-11.

The monitor system has been elaborated in order that it is also able to perform other tasks:

- for the measurement of the activity of computer systems
- as a diagnostic system of computer networks
- for the examination of electronic telephone exchanges.

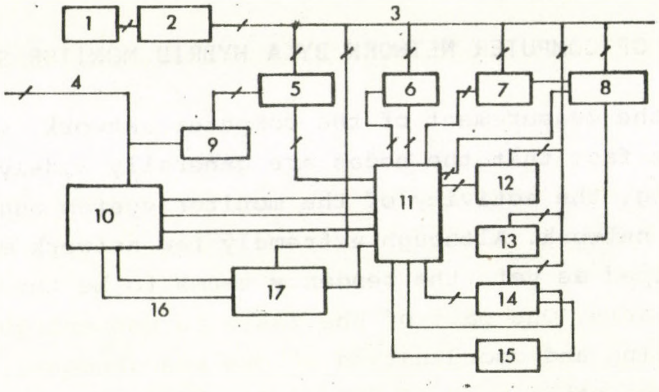


Fig. 7 *Remote controlled hybrid monitor*

1 PDP-11
2 INTERFACE
3 MONIBUS
4 CHANNEL
5 ASSOCIATIVE ARRAY
6 SWITCH MATRIX
7 TIMING
8 INTERRUPT
9 CHARACTER DETECTOR
10 COMPUTER TO BE MEASURED
11 CONTROLLER
12 TIME-AND-EVENT COUNTER
13 HISTOGRAM GENERATOR
14 LOGIC UNIT
15 CLOCK
16 DATA OR ADDRESS BUS
17 COMPARATOR

5. MEASUREMENT EXPERIENCES OF ARPA

The biggest and most mentioned computer network is ARPA for the establishment of which great forces were mobilized. One purpose of its establishment was to provide knowledge of the networks, therefore an extremely large number of measurements were made by ARPA. The measurements gave a snapshot of the behaviour of the network and served as a basis for the determination of the network models and of the different network parameters. The majority of the measurements were performed by software monitors. Following the suggestions of G.D. Cole [2] the measurement tools, methods enumerated below were used:

- accumulated statistics
- snapshot statistics
- trace data
- status reports.

The accumulated statistics routines were most frequently used as they give a comprehensive picture on every node. These routines collect the characteristic data of the traffic between HOST and IMP, between IMP and IMP; the length of messages, the average number of packets, the numerical data of the control and other accompanying signals. /ACK, RFNM, etc./. The results can be presented in form of histograms, as mean values or, as single items of numerical data fo moments.

The snapshot statistics method observes the routeing tables and the lengths of queues. The results are determined and distributed to IMP-s. The measurement is performed every 0.82 secs. This time interval is a reasonable compromise thus the measurement does not yet significantly disturb the traffic while a sufficiantly good picture can be obtained on the sequence of the status changes.

The trace data make it possible to follow the path of the message along the network. The typical data of such a trace list are the following:

- the arrival time and the departure time of the message
- the time of positive acknowledgement
- code number of the source and destination
- number of messages
- number of packets
- the priority status.

The status reports fix the activity of the nodes, resources and channels as well as the information belonging to them.

A tool for the network measurement is the artificial traffic generation the routines of which are located in the IMPs and measurement centre. By means of the artificial traffic generator messages can be sent to several destinations through 63 links. The parameters of the messages can be changed.

The measurements of message traffic began in 1971. Since the message traffic icreased significantly between 1971 and 1973 /Fig. 8/ the network was continuously measured for 7 days in August, 1973. A total of 26 million messages, together 6.3 billion bits were sent in 7 days via the network.

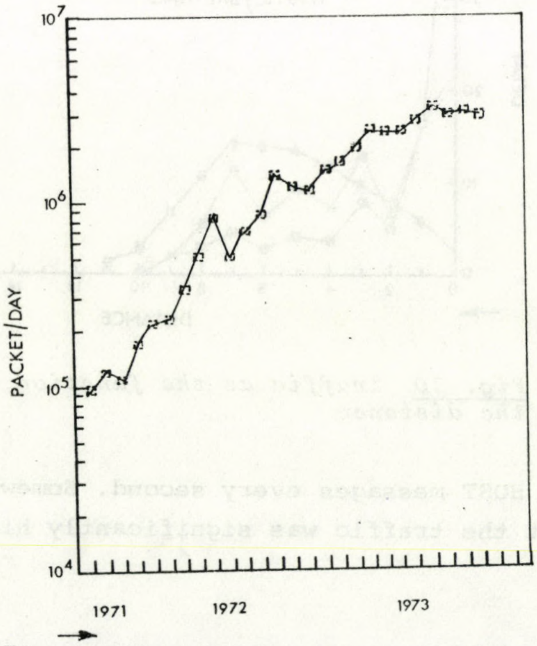


Fig. 8 *Traffic increase of ARPA*

During the attempt [4] statistical data collected from each point was sent every 7 minutes to the measurement centre for processing. The dual purposes of the measurement was the observation of the performance of the network and the mapping of the traffic parameters. First of all the following characteristics were measured:

- distribution of the message and packet length,
- average message delay,

- length of the route weighted by the average traffic,
- channel utilization,
- most popular nodes and channels,
- departure points and destinations of most frequently sent messages.

At the end of the experiment very many interesting measurement results were available for the researchers. We should like to consider some of these. In Fig. 9 the logarithmic histogram of the HOST message length expressed in packets can be seen. According to the histogram the average length of the messages is 1.12 packets i.e. 243 bits. Thus there are only a very few messages consisting of several packets, moreover, most of the messages consisting of a single packet are also short.

The relationship between the traffic and distance can be seen in Fig. 10. A surprisingly large part, about 22 per cent of the traffic, takes part between two such HOSTs which belong to the same IMP. 16 per cent of the traffic takes place between two nodes.

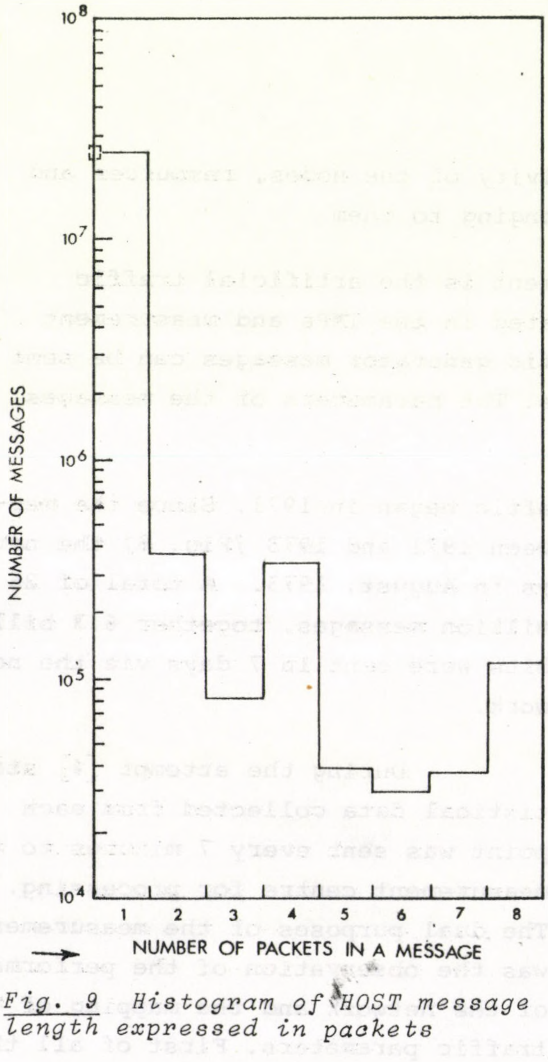


Fig. 9 Histogram of HOST message length expressed in packets

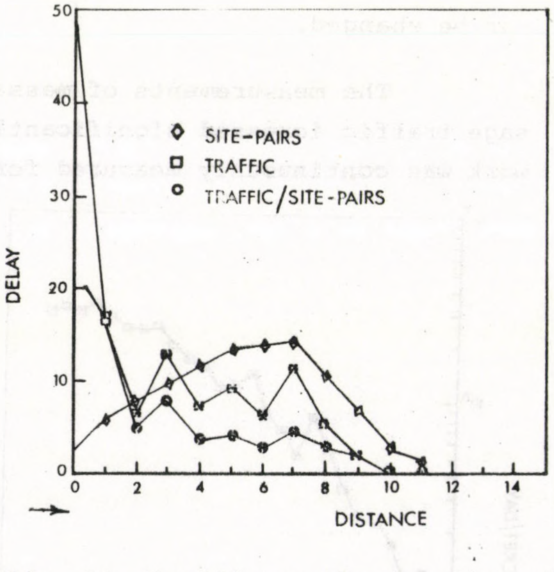


Fig. 10 Traffic as the function of the distance

Figure 11 shows the arrival of HOST messages every second. Somewhat to our surprice, it was experienced that the traffic was significantly higher on Mondays.

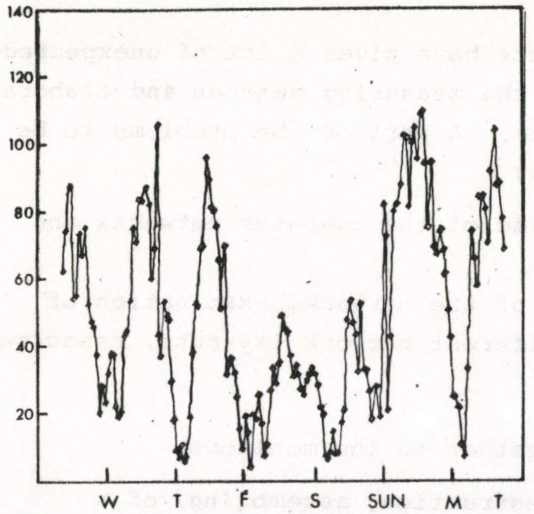


Fig. 11 Number of HOST messages every second

In Fig. 12 the business of "favoured" destinations can be seen in the function of the days.

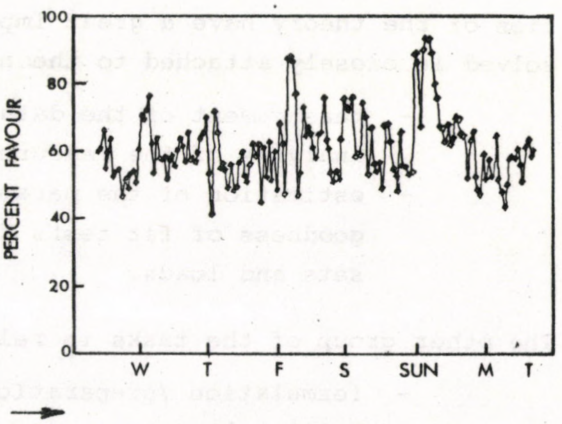


Fig. 12 Business of the "favoured" destinations

Figure 13 shows the delay of the messages as a function of the days. Here the delay time was as that time which passes between the entry of a message the network and the arrival of the acknowledgement from the destination to the source /round-trip delay/.

During the course of the measurement of one week duration a number of valuable data were collected. These one-week period measurements were repeated several times; the results were always similar.

It follows from the experiments that the efficiency of the network would improve in the case of smaller packet length and therefore smaller IMP buffers. It can be seen too, that the lines are not over-exploited and that the delay times are so small that they cannot be sensed by the average user.

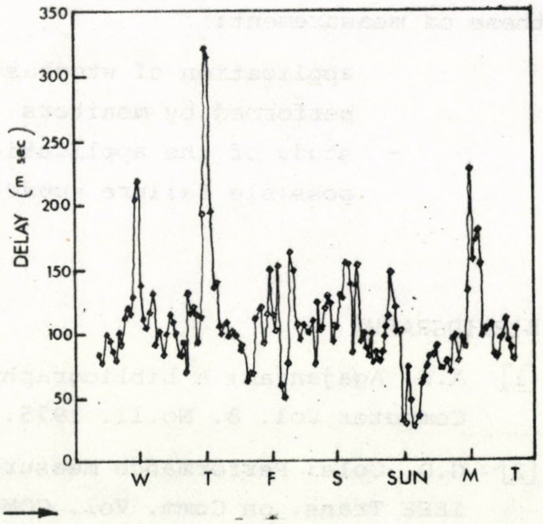


Fig.13 Delay of the messages as a function of the days

The significance of the experiment is also increased by the fact that on the ground of the statistic data the validity limits, of the model describing the delay of messages consisting of one and more packets have also been examined and a simplified model described which is a good approximation of the measured results.

6. PROBLEMS TO BE SOLVED

The different network measurements have given a lot of unexpected results therefore further development of the measuring methods and elaboration of the theory have a great importance. A part of the problems to be solved is closely attached to the network:

- measurement of the data traffic of the computer networks and analysis of the measured data
- estimation of the parameters of the network, examination of goodness of fit tests for different network lay-outs, resource sets and loads.

The other group of the tasks is related rather to the monitors:

- formulation /preparation, construction, assembling/ of a monitor language
- design of a self-monitoring computer system and network
- examination of parallelism and contrasts between the monitor attached to the computer and the remote controlled monitor system testing the computer network.

Among the problems to be solved the most interesting are perhaps those belonging to the interdisciplinary area of computer technique and these of measurement:

- application of stochastic measuring principle in the measurements performed by monitors
- study of the application of the deterministic measuring principles
- possible failure sources in the light of measurement technique.

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