SOFTWARE FOR COMPUTER CONTROL

Edited by

M. NOVAK

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M. NOVAK

General Computing Centre, Prague, Czechoslovakia

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The Editor

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FOREWORD

During the last fifteen, years, digital computers (maxi, mini, micro) have been increasingly used to control various industrial processes and experiments. Design and programming of process control systems is still a very difficult job, as heterogeneous hardware is used for this purpose and the process control algorithms are not yet fully clear. In order to find the best way of programming these process control systems, a triannual international symposium, IFAC/IFIP Software for Computer Control (SOCOCO), was organised. Following the first successful SOCOCO '76 at Tallin, the

2nd IFAC/IFIP Symposium SOCOCO '79

was held in Prague from 11 to 15 June, 1979. The interest in this new sector of computer sciences (informatics) can be illustrated by the fact that the number of papers submitted to the IPC for SOCOCO '79 was three times that for SOCOCO '76. The three years following SOCOCO '76 brought about a rapid development of process control software especially in microcomputers, new access to standardization of computer control software and to exploitation of distributed computer systems, which have a multilevel hierarchical structure.

This proceeding contains papers presented at SOCOCO '79 grouped according to the symposium topics. The first part includes four main lectures:

J. Puzman, P. Porizek (Czechoslovakia)
Communication control in computer networks (case study)

G. Musstopf (FRG), H. Orlowski (Poland), B. Tamm (USSR)
Program generators for process control applications (survey paper)

G. Musstopf (FRG)
Microprocessor hardward and software (tutorial)

I.C. Pyle (United Kingdom)
Methods for the design of control software (survey paper)

and presentations from the following areas:

software for microprocessors, process control, experiment control, real-time languages and operating systems.

The papers from the sessions

algorithms for computer control, computer aided design, interactive systems, application of computer control in sciences

are included into the second part.

We hope that the publication of papers presented by specialists from 21 countries will make a major contribution to the development of these important areas of computer sciences from the practical as well as from the theoretical points of view.

Jan Sedlák
IPC SOCOCO '79

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The Application of Computer Control in Science

Algorithms for Computer Control

COMMUNICATION CONTROL IN COMPUTER NETWORKS

J. F. Pužman and R. Pořízek*

Federal Ministry of Technology and Investments, Prague, Czechoslovakia
**Institute of Applied Cybernetics, Bratislava, Czechoslovakia*

Abstract. The problem of controlling data exchange in computer networks with respect to real, in particular stochastic, interferences, and user's requirements, expressed by performance criteria, is discussed. First, the control problem is studied in the 2-station model by means of the concept of communication functions and protocols the latter being a tool for implementing the relevant communication functions. In complex computer networks a hierarchical decomposition of the communication control into layers facilitates to implement the control hardware and software. As a universal model a reference network architecture is introduced enabling to describe all types of communication and their control in each layer and between adjacent layers.

Keywords. Computer networks; multi-access systems; telecommunication; computer network architecture; communication computer applications.

INTRODUCTION

The growing number of computer networks makes it necessary to know more about elements and structures of these networks, their cooperation and interrelation. Computer networks primarily represent an advanced type of multi-access systems and form the basis for distributed data bases.

The configuration of a computer network consists of host computers and terminals interconnected mutually via a data communication subsystem. Such a subsystem may consists of access elements like FEPs, TIPs, IMPs, of concentrating and switching elements (MUXs, packet switching nodes, exchanges, PABXs), data transmission media such as telephone and telegraph (telex) lines with data sets, etc. The communication subsystem is either created from own means (excluding the lines that belong mostly to the PTT) or uses the services of public data networks if they are available. In all cases, however, some communication control governing the data exchange between elements of computer network or communicating entities is necessary. In contradistinction to the data transfer between elements of a data processing equipment taking place in short distances practically without any disturbancies, computer networks require long distance data exchange over unreliable communication means.
In computer networks there are many pairs of entitites that need to communicate, i. e. to exchange blocks of data (messages, letters, packets), between each other, e. g. software modules or processes, a terminal and a computer, transport stations, node communication computers. Regardless of the different nature of enumerated communication entities their action has the common aim: to fulfil the specified requirements even in the presence of outer interferences. Therefore it seems to be possible to study such a communication from a common viewpoint.

Computer networks have generated new problems not only in the hardware area but mainly with respect to the complex structure, the organization and the coordination of elements having common features of both data processing and data communication systems. This fact does not surprise because appropriate theoretical tools and new techniques needed to solve them are still missing. Frank (1975) has outlined the main problems after dividing them into two categories: difficult but tractable ones, and exceptionally complex ones. Among the latter a network control theory that is joined with protocols, measurements and performance evaluation, is reckoned. Therefore, protocols, network architectures, communication functions and services belong to the most discussed topics.

The purpose of this paper is to contribute a little to the data communication control. The aim is to outline difficulties connected with the control of communication and to define the relation between computer network performance and its communication control. The concept of communication function is reintroduced as a foundation-stone of communication control protocols that are further analysed and precisely described. Finally, as the control is cleared up on the simplest 2-station communication model, the last section returns to the primary system - the computer network and is devoted to its architecture comprising a communication control structure.

THE CONTROL OF COMMUNICATION

In order to simplify our considerations let us first deal with the following model. We shall call the entities - the stations, and the communication medium that connects them - - the data link. The data link can be either physical or virtual. The elementary communication system thus consists of one pair of stations and of a data link or parallel data links (Fig. 1).

Fig. 1. 2-station communication model.

The communication system suffers from many disturbances, in particular of a stochastic nature that influence more or less all its parts. Data messages having to be exchanged differ in their volumes (number of bytes, bits). The occurrence of data messages in stations is random so that the magnitude of data flow varies from case to case and from time to time. Equipment of the system structure is not absolutely reliable, data links suffer from noise, drop-outs, fading, etc. which causes an erroneous receipt.

On the other hand the user has several requirements that he wants to fulfil in the communication system. He may determine the readiness measured e. g., by the response, delivery or access time for certain lengths of data messages. Also he may require some accuracy given by the residual error rate, the reliability expressed e. g., by the mean time between failures or by an availability, and the cost that, being chosen appropriately, involves the degree of utilization and efficiency (Pužman, 1977).

As the communication system is stochastic the required values cannot be stated accurately but with some ranges that must be kept by the system (e.g., the maximum response time, the minimum probability of error). All requirements form components of the communication system performance.

It is clear that the performance of real communication system varies necessarily due to varying disturbancies, so that to keep the performance values in prescribed limits the communication control must be introduced.

The communication control is a system of actions that serve to maintain the communication according to reguired performance values.

We shall give here neither a formal definition of communication control nor a formulation of control problem (called also a satisfaction problem) because they can be found e. g., in (Mesarovic and Takahara, 1975). But we must mention the principal features concerning the control of communication.

While the classical control problem is solved "out of a controlled process" that means the control observes a process and governs it directly by its intervention, the long distance between stations in a communication system does not enable the direct influence and must utilize the data link itself. But the data link partly carries data, partly suffers from unreliability so that control signals must be squeezed into data and protected against noise, failures, and perturbations.

Another problem arises when the performance is multivalued, i. e. it is expressed by several components which form in general (in terms of (Mesarovic and Takahara, 1975)) a cohesive set (the response time increases with decreasing residual error rate). The dependency between performance and disturbance components is very complex and not yet satisfactorily expressed. Moreover, it is impossible to achieve an arbitrary set of values of performance criteria for some disturbance value so that the communication system need not be completely controllable.

The role of communication control is now clear: if the problem formulation corresponds to some controllable conditions then the communication control must govern the real communication system in order to follow the user's required performance. The complexity of such a problem even for a 2-station system consists in the following.

Suppose the value of one disturbance component begins to change worsening performance so that control intervention is needed. But the influence of control on the communication system cannot react in such a way that only one performance criterion will be affected and other criteria values remain unchanged. The interdependence of performance criteria causes the complex behaviour of many or all their values so that further intervention must be introduced in order to eliminate undersirable changes of them even when the original disturbance has stopped its influence. If we admit that almost all performance component values cannot be achieved at the same time (and this actually happens) the control must find out some compromise of solutions.

Although many types of disturbances affect the communication system there seems to exist a way out of the impasse: to decompose the control into less complex actions and to solve each problem separately. One approach is to deal with communication functions that will be the subject of the next section.

Besides the outer unpropitious disturbances there are other factors that are hidden in the user's requirements and in the communication system performance and demand the corresponding control. For example, human intervention into the computer network is undesirable in contradistinction to public networks like telephone or telex where in turn the human factor plays an important role. To mechanize the whole action of computer network is quite a natural requirement that is necessary in order to utilize efficiently up-to-date data resources.

The cost does not apply only to the control itself but also to the whole system. The cheaper the communication system is, the more sophisticated its design must be. Each computer network is a very expensive system and the predominant cost being expended on it concerns the communication, in particular data links and link buffers. The effort in economizing cost must be concentrated in this field. To share data link and buffer capacities is one way, another way is to reduce transmitted data and to distribute the intelligence far from CPUs. The communication control must embrace many aspects that are appearing in present computer networks and will appear in the future.

COMMUNICATION FUNCTIONS

The notion of a communication function is not new. First it appeared in 1972 (Elie, 1972) although intuitively it has been dealt with much earlier, practically hand in hand with the data transmission development. Nevertheless, the precise definition of communication function has not been stated, perhaps for its clear intuitive meaning.

Elie (1972) in his paper has considered a communication function to be the transformation of information being generated by a source which makes it acceptable by a sink. Such an interpretation seems to be very close to the real action of communication system because the whole communication operating with stations at the end of data link can be comprehended as a transformation facility which conforms the results of communication to given specifications of users (Fig. 2). Thus, the term function is quite appropriate.

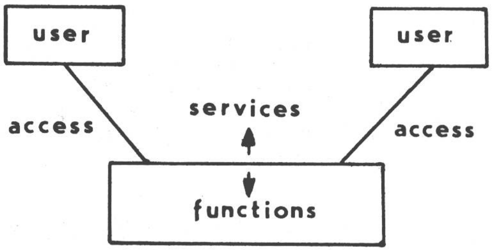

Fig. 2. Functions and services.

If we admit that the communication function is a transformation we must ask how to define it. First, the domain and the range of communication function must be determined. We may imagine that the communication function operates in that way that it changes one state of communication system into another. Thus, the domain is a set of starting states while the range is a set of final ones. The states can be described in many ways, e. g. by values of performance criteria, by properties of communication elements, by the behaviour of communication systems, etc. After determining accurately corresponding states the communication function is a set of rules transforming the starting states into the final states.

Besides the starting and final states of the whole communication it is possible to find out more internal well-defined starting and final states if we carefuly follow the course of communication. The first control action is to establish a data link in a sufficiently short time period. The final state of it may be done by the existence of a physical or a virtual link and the time limit within that the link must be established. Such a final state is at the same time a starting point for synchronizing (bit, byte, block and/or message phasing) a receiver on a transmitter in both stations (if necessary).

These control actions or communication functions are necessary in order to realize the communication in general. There are, however, other optional communication functions the use of which depends on the specific requirements. For example, after the synchronization process the fragmentation of data message into shorter blocks enables to put through an amount of data within a short time period if more than one path between both stations are established (then an appropriate routing must follow). During the data exchange the error control takes place with the aim of increasing the accuracy, etc. For those who are acquainted at least a little with data communications, the following examples will help to understand the principles of the decomposition of communication control operation by means of communication functions.

The simplest data message transfer over a leased line may consist of synchronization establishment - transmission opening - block phasing-message fragmentation - block formatting - error recovery - message reassembling - - transmission closing.

The packet delivery over a packet switching network would proceed from packet formatting through routing, packet phasing, flow and error control. Using a multiaccess communication system then after the packet formatting an access to a slot, a buffer management and a reservation of another slot is inserted.

If we adopt the communication function as a control action tending to improve the performance value after some undesirable interference then the communication control is a system of communication functions. Moreover, if communication functions act sequentially (and almost all communication functions are of that nature) we may conclude the communication control is in fact an ordered system of communication functions. On the other hand, each communication function can be defined by a system of rules of station behaviour (note, the control act via both stations before,during and after a data transfer) so that the same holds for the communication control. We shall return to this fact in the next section.

It remains to state the relation between outer disturbances and a communication system performance expressed by means of communication functions. The complexity of such a task will be shown on a relatively simple example.

Let us consider the subset of main optional communication functions chosen from (Pořízek and Pužman, 1978):
-error control (a set of rules to detect transmission and/or processing errors and to correct them),
-flow control (a set of rules to govern the rate of transmitter according to the receiver possibility of receipt),
-routing control (a set of rules to direct data blocks to outgoing data links),
-capacity assignment control (a set of rules to share the data link capacity among several data messages),
-fragmention/reassembly control (a set of rules to split up a data message into fragments, to envelop each fragment and to form a block/ to relieve received blocks of envelopes, to sequence fragments into original data message),
-recovery control (a set of rules to identify exceptional states and to pass over the control to higher level).

The influence of each communication function on global performance criteria is shown in Table 1 where + designates the improving while - stands for the worsening of performance criteria, e. g. the increasing of the cost, (O indicates that the influence can be neglected). For example, the error control increases the overhead of transmitted data due to check bits being added to information bits and due to retransmissions after detecting an error so that the readiness is worsened. But at the same time it increases naturally the accuracy and of course the cost, while the flow control leaves practically the accuracy and the reliability unchanged and decreases the cost owing to the shortening of buffer capacities, etc.

TABLE 1 The Influence of Communication Functions on Global Performance Criteria

	readiness	accuracy	reliability	cost
error control	-	+	O	-
flow control	-	O	O	+
routing control	+	O	+	O
capacity assignment control	-	O	-	+
fragmentation/reassembly control	+	+	O	+
recovery control	+	+	+	O

Table 1 shows the complex interplay of influences of communication functions on performance criteria. Suppose we must improve an accuracy. We may introduce an error control and a fragmentation/reassembly control (in the case of long data messages both are necessary). But, at the same time, the error control increases both the response time (worsens the readiness) and the cost (the fragmentation/reassembly cannot counterbalance the error control), so that the routing control is necessary for improving the readiness, and the capacity assignment control may decrease the cost.

Although tables similar to Table 1 can be constructed for other communication functions and other performance criteria, and many measurements have been performed in real computer networks, nevertheless the exact functional relation between the methods of realizing communication functions and the performance criteria having also a practical use is far from a solution. This problem comprises the basic step in the development of communication control theory.

The concept of communication function is very close to another notion - the communication service. A transmission facility realizing some communication functions offers a service or services to users,being its subscribers,through an access (see Fig. 2).

We shall,for our purposes, put an equal sign between the communication function and the communication service although the verbal interpretation of both concepts may be different. We are speaking about physical data link establishment/disconnection as about the communication function but from the subscriber's viewpoint it is expressed by the communication service "line switching".

As the line switching and virtual call services resemble the PTT telephone service and the same holds for the datagram and PTT post service, and as each class of communication services has its specified communication functions, the following examples show us the differences between both services on the basis of implemented communication functions.

The telephone service starts with the physical or virtual link establishment, then it may be necessary to establish the bit phasing and to open the transmission. As the established link is able to carry several independent calls (channels) the efficiency (cost) forces to share the link with other calls and therefore one must control the capacity assignment (e. g. by means of multiplexing, polling, multiaccess). The data exchange necessitates the error and flow control accompanied by the message fragmentation, formatting and buffer management. The reassembling with the sequencing into the same message as being sent is a main feature of a telephone service. Finally, the closing of a transmission and the disconnection of a link are inverse functions of the transmission opening and link establishment, respectively.

The post service is very similar to the PTT service of packet delivery. It necessitates the message fragmentation (but not correct reassembling), transformation of formats, headers, addresses, etc. (if necessary), the searching of an appropriate channel direction (routing). After determining the link by routing all communication functions concerning the packet (block) delivery over a data link with required readiness, accuracy, reliability and cost have to operate.

For both services the exceptional state recovery is a very useful communi-