ISSN: 2617-2070 (Print) ; 2617-2070 (Online)
Journal of Advanced Sciences and Engineering Technologies
Available online at: http://jaset.isnra.org/
Journal of Advanced Sciences and Eng. Technologies
JASET

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The task of managing flows in a communication network of the X.25 protocol

Keywords
managing flows, communication network
X.25 interface
Data Circuit terminating Equipment

ARTICLE INFO

Article history:
Received 01 September 2020
Accepted 01- October -2020

Available online 10– October 2020

DOI:
http://dx.doi.org/10.32441/jaset.03.02.03

A B S T R A C T

One of the most established and well-known standards for packet switched networks are the international standard X.25, The X.25 Recommendation defines the interface requirements between the user equipment (such as a terminal, bridge, router, and computer) and a packet switching network for data exchange X.25 network provides an efficient way to transfer data within one region, the country and even all over the world. The synchronous data transfer with a speed of up to 64 Kbps. The X.25 standards provides automatic error detection and correction, which allows X.25 networks to work effectively even in regions where the quality of communication lines is low. The X.25 interface provides Access to the remote user to the host computer (host). The X.25 standard describes the interface between the data entry equipment - DTE (Data Terminal Equipment) and data network equipment - DCE (Data Circuit terminating Equipment). Bridges, routers, terminals, personal computers (PCs), workstations are an example of equipment that can function as a (DTE) . When it is connected to a packet switched network. DTE provides the user part of the user-network interface. The equipment to which the DTE is connected is called DCE. DCE provides the network part of the user-network interface. Each DTE has its own DCE. However, several DTE devices can be connected to the same DCE. DTE-DTE connection is invalid; communication is only possible between DTE-DCE and DCE-DCE

Introduction

The X.25 standard defines the interface between the user equipment and the packet switching network and does not affect the protocols and interfaces used internally. X.25 defines the user interface with the network in such a way that the internal operations of the network and network protocols are transparent. As a result, the term "network X. 25" is not entirely accurate, since the X.25 standard does not actually determine the internal behavior of the network.

The X.25 standard is consistent with the recommendations of the International Organization for Standardization (ISO) seven-level open system interconnection (OSI) model [1,2,3]. This model is the basis for developing standards that allow heterogeneous systems to communicate with each other.

We will describe three lower levels of OSI, with which the X.25 standard is related

Network layer. Responsible for transferring information from one end-user to another through the network. The network layer defines the physical path that the packet will pass from the starting point to the destination. At the network level, there are two communication models:

• A model that is oriented towards the pre-establishment of a logical connection. The connection remains active while the data is being transmitted, and terminates as soon as transmission ends. The service provided by a network oriented to a pre-connection includes setting up a logical connection, data transmission and disconnection. For this model, the network layer must define the protocols that provide such a service;

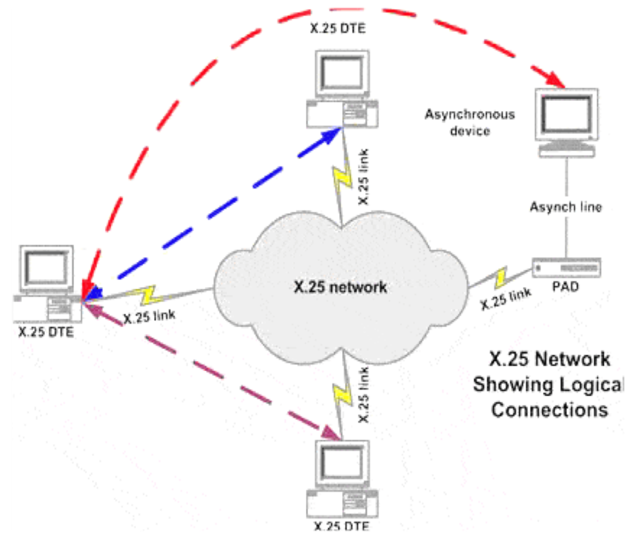

Fig1 X.25 Packet Switched networks allow remote devices to communicate

• A model that does not require a logical connection before the data is transferred. It resembles an ordinary mail service when a user immediately sends a packet to the network with information without establishing a connection with the endpoint. Each packet is independently promoted over the network in accordance with the destination address. Thus, with independent distribution, packets can arrive at the end point in a disordered manner.

Level 2. Data link layer (Data link layer). Provides error-free data transmission through one physical link connecting

a pair of DTE devices - DCE. Some functions of level 2:

• recognizing the boundaries of frames (frames);

• flow control;

• Detection of errors at the physical level.

The functions of the levels considered are significantly different: level 2 is responsible for the error-free transfer of information between the DTE and the network, and level 3 is responsible for routing the data throughout the network [4,5,6,7]

Level 1

. Physical layer. Provides transmission of an unstructured bit sequence through a physical environment. It is the physical layer that carries the signals of all the upper levels. Some functions of level 1:

• determining the size and shape of physical connectors;

• pinning physical connector contacts to electrical signals;

• Electrical levels of the coded signals.

The first two levels of X.25 almost exactly correspond to the physical level and level of data transmission of the OSI model. However, the packet level of X.25 differs slightly from the network layer of the OSI, since it contains additional functions characteristic of higher levels of the OSI model. The packet level X.25 manages the channels and the stream, sending the acknowledgment of receipt

Packages, i.e., functions traditionally attributed to the transport layer of the OSI.

Three levels of X.25 perform the following functions:

• The packet layer forms the packet, and also performs the procedure for transmitting packets through the network. Functional support at this level includes: nesting multiple logical channels into one physical chain; flow control at the packet level; establishing and breaking virtual connections; support for specific negotiable properties. The unit transmitted at the packet level is a packet;

• The link layer defines procedures that ensure reliable data transfer through the channel between the DTE and the packet switched network. The unit transmitted at this level is the frame;

• The physical layer provides mechanical, electrical and procedural conditions for data transmission over a physical DTE-DCE connection. The unit transmitted at the physical level is a bit.

Approach

The task of monitoring and managing the network

Constant exposure to various kinds of disturbances, which leads to the failure of switching nodes and communication channels, errors in the transmitted messages, to the random nature of the circulating data streams Under these conditions, the task of monitoring and managing SAP is to ensure the transmission of the maximum number of messages with the required quality (reliability, speed, reliability). Under the number of messages sent over a certain time interval with the required quality is meant the performance of the SPD, and under the maximum possible performance - the network bandwidth. The bandwidth (PS) of the network depends on the control and management of the network. potentially possible and realized PS [1, 7,]. The more perfect of the networks control and management system, the closer the realized throughput to the potential [8]

The Operation management of SAP is understood as the process of dynamic organization of such a targeted impact on network elements, as a result of which the network provides the maximum throughput. The operational control system must implement many functions, including managing the distribution of data flows. the control of the distribution of data streams is meant a set of protocols, procedures and algorithms for routing, the data distribution management sub-system is responsible for organizing incoming packets on the packet switching centers, distributing incoming queues to the outgoing branches and recipients of information, redistributing outgoing queues in the event of channel failures, and distribution of packets over channels in multi-channel branches[9].

Thus, routing is the most important factor determining the efficiency of the packet switching network, since it affects the time of packet delivery, throughput, and the use of nodes and communication links. The Routing methods can be considered as a set of rules that determine how packets pass through the network. According rules, each node selects the outgoing communication line and transmits the packet to the neighboring node. The purpose of routing is to find such a set of paths between sources and destinations with given input streams and network topology, which ensures efficient use of network resources and a specified quality of user service. At the same time, routing algorithms function successfully, while the intensity of the load entering the network does not exceed some "permissible" level. The complexity of routing algorithms depends to a large extent on the topology of the network, the nature of the input stream, the accepted flow maintenance discipline, and the requirements for the quality of user services [10,11,12]

Overview of Routing Techniques

All routing methods can be divided into two large group's directional and non-directional search of paths. In turn, the methods of directional search are divided into fixed (deterministic) and adaptive (dynamic), while the adaptive routing methods mean the choice of the path of data transmission over the network, taking into account the change in the state of nodes and communication channels, and for fixed routing methods, the path of data transfer via the network it is predetermined and does not change in the future.

Non-directional search methods include the random search method, the avalanche routing method, and the fastest transmission method.

The method of random search assumes that the packet on the node selects any one channel coming out from it, over which the packet is transmitted. Thus, the packet wanders around the network until it reaches the destination node. This method is simple, but not very effective, so it does not find application.

The avalanche routing method consists in the fact that the node that needs to transmit the packet multiplies it and sends it to all outgoing directions, in addition to the direction from which this packet came, etc. To limit the number of consecutive transmissions, this method uses a count of the number of steps taken. Upon reaching a certain value of the counter, the packet is destroyed. Advantage of the avalanche method lies in the ultimate reliability and efficiency of bringing packets and absolute independence from the structure. However, these advantages are achieved at the cost of a significant overload of the network with copies of packages. This method is effective in the transmission of circular messages and with frequent failures of network elements.

According to the method of fast routing, packets on the node try to leave it as soon as possible. This method does not provide the choice of the best ways to communicate information.

The methods of fixed routing give good results for weakly loaded networks with fixed traffic. However, in networks where the input load and the network structure are subject to frequent changes, the effectiveness of fixed methods drops sharply.Currently, two modes of packet transmission have spread on the PD-KP networks. The first one (datagram mode) is based on the independent transmission of each packet, even if they are parts of one message. In this case, each header includes a header containing the recipient's address and other service attributes. If adaptive routing is used on the network, packets of the same message can be sent on different routes and be on the road at different times, which can lead to a violation of the original sequence. In networks where the order of delivery of packets to addressees is important, special measures should be applied to restore the correct sequence of packets.The second mode, virtual, involves presetting the transmission route of the entire message using a special service package. Packets transmitted over a virtual channel are not independent, so include a shortened header. In this case, the order of the packets arriving at the destination address is ensured.

The protocols of datagram networks do not necessarily require the storage of a sequence of transmitted packets. Und Adaptive routing these conditions, adaptive routing can be used in its entirety.

Adaptive Routing

Adaptive routing allows you to adapt to the constantly changing situation, takes into account the failure and recovery of network elements, as well as connecting to the network and leaving it new nodes. In general, adaptive routing must meet the requirements for adaptation to load fluctuations and network structure changes, ensure that there are no looping cycles and that detours are performed around the SPD overload zones.

Thus, the task of adaptive routing is to define a procedure that corrects the routing matrices in accordance with changes in the network. This procedure includes the following functions:

• monitoring the status of the network;

• Collection of service information about the network status at the point of decision making:

• Calculation of routing tables;

• Selection of packet routes according to the computed tables.

Adaptation costs are made up of the costs of collecting and sending service information about the network status and computing resources for the calculation of route tables [13]. The more the network is subject to sudden fluctuations in load and frequent changes in the structure, the more dynamic the routing algorithm should be.

To make optimal routing decisions on the nodes, you need to have reliable information about the situation in the network. The main difficulty is the commensurability of the rate of change of the situation in the network with the speed of information transfer about these changes. Since on the nodes when making routing decisions the information about the state of the network is obsolete, in most cases it is not the instantaneous values of the monitored parameters that are used, but their average values over a certain period of time. This is due to the fact that, as the experience of operating the ARPA network has shown, an excessively fast reaction to instantaneous load fluctuations leads to an unstable operation of the routing algorithm and to a large expense for the exchange of service information.

According to the information used to make decisions about the choice of routes, adaptive methods are divided into local, distributed, centralized and hybrid (combined). There are many adaptive routing algorithms [14]. Let's consider some of them.

From the point of view of development and implementation, the simplest methods are adaptive routing, which build their solutions only on the basis of their available in each packet switching center (PCU) information. Such algorithms belong to the local class. The information needed to make a decision is the routing tables loaded into the central station, information about the current state of the output channels and the queue lengths of packets waiting to be transmitted on each of the channels. Information about the status of other network components is not used. The most famous algorithm of this class is called "the shortest turn + offset" According to this algorithm, the route is selected from the set of possible routing table tables, using calculations based on information on queue lengths and network topology reflecting the "offset", i.e. preference for the best channels to reach one or another addressee. The main question that arises when using this algorithm is the choice of the value of "offset". There are also other algorithms related to this class - "load sharing method", "overflow method", which are similar in their characteristics to the previous one. A common drawback of this class of algorithms is the slow response to events occurring in remote parts of the network, such as network components failures, local overloads.In a network with centralized routing, a network management center (NCC) is created that determines the direction of traffic of packets through the network. Packet switches in this case should not be as perfect as, which allows reducing the cost. However, this approach is vulnerable to possible breakdowns. There is one more drawback of the centralized method of routing - inertia. This drawback arises from the fact that the works on the basis of partially obsolete information and issues control directives, which by the time they are received on the ground will be even more obsolete.

Distributed routing control ensures greater network elasticity, since each node takes its own decision to route packets without any relation to the NCC. Distributed routing is more complex and requires a large amount of computation. For example, we can cite such methods of distributed routing: the method of reliefs, the algorithm for routing the ARPA network, the algorithm for differentiating priority flows.

Hybrid routing methods combine the advantages of distributed and centralized algorithms. The most famous method of hybrid routing is delta routing. Also known is the hierarchical principle of routing [14], following which the network is divided into several subnets. Each subnet implements centralized routing, and the data exchange between the NCC of the subnets occurs over broadband channels using

Adaptive Routing Algorithm in the Switching Network

Formulation of the problem

A distributed computer network is considered, its structure is defined as a digraph G = {X, E}, where X = {xi} are network nodes, E = {(r, s)} is a set of communication channels connecting nodes xr and xs, is given requirements matrix H = || hij ||, hij - the required flow (pack. / s) That must be transferred from xi to xj. The bandwidths of the communication channels μrs are set.

Key assumptions on the network:

- Incoming claims flows - Poisson;

• Service time in communication channels is deterministic;

Communication channels are unreliable, the failure rate of the communication channel, and the recovery rate. In this case, the mean time between failures, and the average recovery time.

The main reliable indicator of the communication channel - availability factor

There are two most important tasks in terms of adaptive routing:

• Correction of route tables for topological changes;

• Correction of route tables when changing flows

3.3.2. Mathematical description of the task

The network structure is given G = {X, E}, where X = {xi} are communication nodes, E = {(r, s)} is the LAN set. Denote by - the set of nodes adjacent to xi, - the set of all destination nodes for xi.

Required for all hosts:

• build matrices P = || pmn || and t = || tmn ||, where m є, and n є, such that

Where is the set of paths from m to n?

Correct P = || pmn || and t = || tmn || when changing the network topology and matrix of requirements H = || hij ||, and, consequently, the current loadings of communication channels in such a way that condition (3.1) is satisfied.

Solution Method

To solve this problem, we use the principle of decentralized routing.

The decentralized (or distributed) routing algorithm uses a special form of routing tables that are located in each MSC [7].

Each CSC exchanges service information only with its neighbors and, based on current information about changes in delays in communication channels, Adjacent nodes are X, Y, Z, the set of all destination nodes is J = {B, C, D, X, Y, Z} (for AHC A).

Denote the set of indices of outgoing physical channels of the CCT A by JA, then JA = {ix, iy, iz}, where ix is the index (address) of the physical channel connecting node A to the adjacent node X, iy is the index of the channel connecting A to Y, iz - linking CCP A with an adjacent node Z.

Fig..2. Packet Switching Center Where JA is the set of outgoing physical channels,

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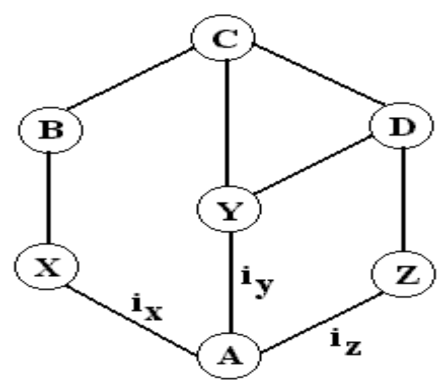

Fig 2. Packet Switching Center Where JA is the set of outgoing physical channels (J) is the set of addresses (indices) of destination nodes

Table 1Main routing table T1

\ j	destination nodes					
I \	X	Y	Z	B	C	D
iX	$P^{A}_{i_x x}$	$P^{A}_{i_x y}$	$P^{A}_{i_x z}$	$P^{A}_{i_x B}$	$P^{A}_{i_x C}$	$P^{A}_{i_x D}$
iY	$P^{A}_{i_y x}$	$P^{A}_{i_y y}$	$P^{A}_{i_y z}$	$P^{A}_{i_y B}$	$P^{A}_{i_y C}$	$P^{A}_{i_y D}$
iZ	$P^{A}_{i_z x}$	$P^{A}_{i_z y}$	$P^{A}_{i_z z}$	$P^{A}_{i_z B}$	$P^{A}_{i_z C}$	$P^{A}_{i_z D}$

If several logical sub channels are organized on one physical channel, then the ix index defines a certain subset of indices and its own subgroup of rows in Table 3.1 will correspond to it.

Here is the priority of channel i for transmitting packets from node A to node j,.The priority of the channel is higher, the smaller the Pij.

The main routing matrix is constructed and adjusted on the basis of an auxiliary table of total delays - Table. 2 and the shortest route table

Tab. 3. consists of the values - the average total delays in the transmission of packets (frames) from node A to node j on channel i. It has a structure similar to the structure table.2.

Since the values change in time, we will denote

In addition, an additional column is introduced in Table 3.2.2 - the average delay in the delivery of packets on channels i.Able 3.2

Auxiliary table of total delays T2

\ j	destination nodes						
I \	X	Y	Z	B	C	D	$\bar{t}_{cp_i}$
iX	$\bar{T}^{A}_{i_x x}$	$\bar{T}^{A}_{i_x y}$	$\bar{T}^{A}_{i_x z}$	$\bar{T}^{A}_{i_x B}$	$\bar{T}^{A}_{i_x C}$	$\bar{T}^{A}_{i_x D}$	$\bar{t}_{i_x}$
iY	$\bar{T}^{A}_{i_y x}$	$\bar{T}^{A}_{i_y y}$	$\bar{T}^{A}_{i_y z}$	$\bar{T}^{A}_{i_y B}$	$\bar{T}^{A}_{i_y C}$	$\bar{T}^{A}_{i_y D}$	$\bar{t}_{i_y}$
iZ	$\bar{T}^{A}_{i_z x}$	$\bar{T}^{A}_{i_z y}$	$\bar{T}^{A}_{i_z z}$	$\bar{T}^{A}_{i_z B}$	$\bar{T}^{A}_{i_z C}$	$\bar{T}^{A}_{i_z D}$	$\bar{t}_{i_z}$

The value is estimated indirectly by the size of the average load in channel i -. In particular, with a fixed packet length (frame) and transmission rate in the bit / s channel,
Contents tab. 3.2, i.e. values is dynamically updated when current downloads change.
Finally, the contents of the table. 3.2 a table of minimum routes T3 is built (Table 3.3), where values are recorded - the minimum elements of the corresponding j-th columns.and also the number of the corresponding channel .Which determines the best route for packet transmission from node A to destination j?

Table of minimum routes T3

j	destination nodes					
	X	Y	Z	B	C	D
$T_i^{(A)}$	$\bar{T}_x$	$\bar{T}_y$	$\bar{T}_z$	$\bar{T}_B$	$\bar{T}_C$	$\bar{T}_D$
i_j^o	i_x^o	i_y^o	i_z^o	i_B^o	i_C^o	i_D^o

On the basis of table 3.2 is filled in table 3.1 as follows. Look at the j-th column of T2 in rows and rank the values in ascending order. Assume that Then we redefine the j-th column of Table 3.1 according to the following rule, Consider the algorithm for dynamic correction of routing tables. The algorithm consists of a preliminary stage and single-type iterations of the adjustment of route tables.

Preliminary stage. Initial construction of tables

At the preliminary stage, the initial construction of tables T1, T2, T3 takes place on the basis of average packet servicing times in communication channels, taking account that all channels are operational.

- We assume. We calculate the value.
- Choose a node to.

1-Fill in the table T2 node to as follows:
2-Choose a pair
3- Calculate the value
3- The average delay in channel i (the average time spent in CS i) is defined as
4-Find

5. Compare the value with a given threshold. If, then the correction tables are not made. If, then, adjust the i-th row of tables T1 and T2 as follows.
6. Calculate the new values (tabl.3.2)
Step 6 is repeated with all the lines i.
7. Adjust the content of table T1 as follows.
7.1. Look at the jth column of T2 and reorder the priorities in table T1 in this way:
For all k Step 7.1 is repeated with all columns j.
8. Next, adjust the table.2.3. To this end, we find from where
If a , then the correction process ends there. If and, then the new values of the minimum delays and the optimal direction of transmission (addresses of outgoing physical channels) are sent to all neighbors of node A (ie, X, Y, Z).
For this purpose, service messages of the form for all j for which are sent to all adjacent nodes for CCU A.
9. Each of the nodes (X, Y, Z) on the basis of this information adjusts the contents of tables

T1, T2, T3 through the physical channel that connects it to node A (i.e.) thus:

$$\overline{T}_{i_{\hat{A}} i}^{X}(t_1) = \overline{T}_{i}^{A}(t_1) + f_{i_{\hat{A}}}^{X}(t_1);$$
$$\overline{T}_{i_{\hat{A}} i}^{Y}(t_1) = \overline{T}_{i}^{A}(t_1) + f_{i_{\hat{A}}}^{Y}(t_1);$$
$$\overline{T}_{i_{\hat{A}} i}^{Z}(t_1) = \overline{T}_{i}^{A}(t_1) + f_{i_{\hat{A}}}^{Z}(t_1).$$

Based on this information, table T1 is adjusted and table T3 is checked. If the content of the table T3 of the node X does not change, i.e. then the node X does not take any further action.

Otherwise, if, SCP X sends service information to all adjacent nodes on outgoing channels about its new delays in the form of service packets of the format (including node A):This process is repeated until table T3 changes at the next ICT at time t1 The specified algorithm converges in a finite number of iterations, and the estimates found converge to the true current values of the shortest delays.

Experimental studies of the algorithm

Test Case Description and Test object

The test object is an adaptive decentralized routing algorithm for a packet switched network with datagram transmission mode. Tests were conducted on a distributed network consisting of 15 nodes and 19 channels (Fig. 2.

Purpose of the test

The purpose of the tests is:

- Algorithm performance check

. Distributed network

The data that were used in the experiment were obtained as a result of the work of the "Net Builder" software package. With the help of this complex, bandwidths of communication channels were calculated with the restriction that the average delivery time of packets over the network would be no more than 5 seconds.

Table 4 Requirement Matrix

0.0	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
2.4	0.0	2.4	2.4	2.4	2.4	2.4	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
2.4	2.4	0.0	2.4	2.4	2.4	2.4	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
2.4	2.4	2.4	0.0	2.4	2.4	2.4	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
2.4	2.4	2.4	2.4	0.0	2.4	2.4	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
2.4	2.4	2.4	2.4	2.4	0.0	2.4	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
2.4	2.4	2.4	2.4	2.4	2.4	0.0	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
2.4	1.6	1.6	1.6	1.6	1.6	1.6	0.0	1.2	1.2	1.2	1.2	1.2	1.2	1.2
2.4	1.6	1.6	1.6	1.6	1.6	1.6	1.2	0.0	1.2	1.2	1.2	1.2	1.2	1.2
2.4	1.6	1.6	1.6	1.6	1.6	1.6	1.2	1.2	0.0	1.2	1.2	1.2	1.2	1.2
2.4	1.6	1.6	1.6	1.6	1.6	1.6	1.2	1.2	1.2	0.0	1.2	1.2	1.2	1.2
2.4	1.6	1.6	1.6	1.6	1.6	1.6	1.2	1.2	1.2	1.2	0.0	1.2	1.2	1.2
2.4	1.6	1.6	1.6	1.6	1.6	1.6	1.2	1.2	1.2	1.2	1.2	0.0	1.2	1.2
2.4	1.6	1.6	1.6	1.6	1.6	1.6	1.2	1.2	1.2	1.2	1.2	1.2	0.0	1.2
2.4	1.6	1.6	1.6	1.6	1.6	1.6	1.2	1.2	1.2	1.2	1.2	1.2	1.2	0.0

Table 5 Average channel loads

No	Meanings	downloads
channel	Received as a result of the program	Received by “Net Builder”
1-2	0.996	0.837
1-9	0.853	0.838
1-12	0.996	0.861
1-13	0.427	0.914
2-3	0.853	0.626
2-4	0.853	0.734
2-6	0.996	0.707
3-4	0.854	0.545
3-15	0.853	0.914
5-10	0.853	0.784
5-14	0.853	0.706
6-14	0.853	0.857
7-8	0.854	0.623
7-12	0.768	0.774
8-9	0.853	0.722
9-11	0.569	0.501
10-12	0.427	0.853
11-12	0.569	0.800
13-15	0.853	0.782

To obtain the simulation results we assume the following:
Simulation time = 100 time units;
Time correction tables = 10 units of time;
Threshold value σ = 0, 005;
We take into account channel failures, while
Failure rate = 0.0001;
Recovery rate = 0.003.

As a result of the program, the following results were obtained:
Average Network Delivery Time: Average network delivery time calculated by the “Net Builder” program:

2.053 sec 4.85 sec
Average table correction time: 0.000518 sec.

From the obtained results, we can see that the average transmission time of packets over the network, calculated using the routing algorithm, is approximately half as much as the average transmission time of packets over the network, calculated by the Net Builder software. This is due to two reasons. When developing the Net Builder software package, it was assumed that the service time in the communication channels was exponentially distributed. This paper assumes that the service time in the channels Is determined. In connection with this fact, the average time of service packets over the network is twice less. In addition, routing algorithms are designed to minimize the average packet delivery time over the network, which also affected the result.

Let us now analyze the values of the received CS downloads. As can be seen from the table. 3.6, the downloads received are somewhat different from the downloads calculated by the "Net Builder" program. This fact is explained by the features of the routing algorithm, since no routing algorithms were used in the "Net Builder" program. Based on the description of decentralized

Routing algorithm, we can conclude that the channels in which the load was overstated, are of higher priority. Consequently, packets were transmitted primarily through these channels, which contributed to an increase in load. Similarly, the channels in which the load was underestimated are less priority, so the packets (if there were any in the nodes) were transmitted through these channels last.

The same conclusions can be drawn based on the routing tables obtained during the program operation [15,16].

Simulation of the network running the routing algorithm

this experiment are:

• checking the possibility of redistribution of flows;

• Comparison of temporal characteristics with static and dynamic routing matrices;

• Verification of the algorithm performance in case of channel failures;

• Identification of features of work and additional characteristics of the algorithm

The order of the experiments

We investigate the work of the dynamic routing algorithm when the flows in the channels change and when the channels fail, which should also lead to a change in the flows. The resulting data is comparable to the static routing algorithm.

To conduct experiments, we consider a fragment of the network (Fig. 3.2.), Consisting of nodes 1, 9, 8, 11, 12, 7, and communication channels connecting them. The capacity of the COP and the matrix of requirements we take the same as in the test case.

Prior to the simulation, routing tables are generated in the nodes. The main routing tables of T1 are given in table.6

	1	2	3	5	6	7	8	9	10	11	12	13	14	15
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1

T1

	1	2	3	4	6	7	8	9	10	11	12	13	14	15
10	0	1	1	1	1	0	0	0	0	0	0	0	1	0
11	1	0	0	0	0	1	1	1	1	1	1	1	0	1

T1 Node 1

	1	2	3	4	5	7	8	9	10	11	12	13	14	15
7	0	0	0	0	1	0	0	0	0	0	0	0	1	0
12	1	1	1	1	0	1	1	1	1	1	1	1	0	1

T1 Node 2

	1	2	3	4	5	6	8	9	10	11	12	13	14	15
13	1	1	1	1	1	1	0	1	1	1	1	1	1	1
14	0	0	0	0	0	0	1	0	0	0	0	0	0	0

T1 Node 3

	1	2	3	4	5	6	7	9	10	11	12	13	14	15
13	1	1	1	1	1	1	0	1	1	1	1	1	1	1
15	0	0	0	0	0	0	1	0	0	0	0	0	0	0

Node 4

	1	2	3	4	5	6	7	8	10	11	12	13	14	15
2	0	0	0	0	0	0	0	1	0	1	0	0	0	0
15	2	2	2	2	2	2	2	0	2	2	2	2	2	2
16	1	1	1	1	1	1	1	1	1	0	1	1	1	1

Node 5

	1	2	3	4	5	6	7	8	9	11	12	13	14	15
10	1	1	1	1	0	1	1	1	1	1	1	1	0	1
17	0	0	0	0	1	0	0	0	0	0	0	0	1	0

The study of the algorithm when changing the transmitted streams

At the beginning of the simulation with a given intensity, packets begin to be generated at node 4 in the direction toward node 12. After 100 units of simulation time have elapsed, packets at nodes 11 and 1 begin to be generated, which are also sent to node 6. The most priority transmission route

Node 6

	1	2	3	4	5	6	7	8	9	10	12	13	14	15
16	1	1	1	1	1	1	1	0	0	1	1	1	1	1
18	0	0	0	0	0	0	0	1	1	0	0	0	0	0

Node 7

	1	2	3	4	5	6	7	8	9	10	11	13	14	15
3	0	0	0	0	1	0	1	0	0	1	1	0	0	0
14	2	2	2	2	2	2	0	3	3	2	3	2	2	2
17	1	1	1	1	0	1	2	2	2	0	2	1	1	1
18	2	2	2	2	2	2	3	1	1	2	0	2	2	2

The study of the algorithm when changing the transmitted streams

At the beginning of the simulation with a given intensity, packets begin to be generated at node 9 in the direction toward node 12. After 100 units of simulation time have elapsed, packets at nodes 11 and 1 begin to be generated, which are also sent to node 7. The most priority transmission route

Packages 9-12 is the route 9-1-12 (see tabl.3.7, 3.15). As channel 9-1 is loaded (Fig. 3.9) with packets 9-12 in embodiments of the algorithm (static and dynamic), channels 9-11 and then 9-8 will be used. This will cause the load on channel 9-11 to increase to a certain value (Fig. 3.7). Channel 9-8 (Fig.3.6) is not used during this period, as it is a lower priority, and the packets have time to be transmitted on more priority channels. At a time equal to 100 units of model time with a given

Intensity starts to generate packets 1-12 and 11-12. In the static variant of the algorithm, the loading of channels 11-12, 1-12 and 1-13 will increase. In the dynamic variant of the algorithm, the routing tables will be corrected in response to the increased load and channels 8-9 and 9-11 will be used more efficiently. From schedule 3.3. it can be seen that the use of a dynamic routing algorithm allows to reduce the average delivery time of packets over the network.

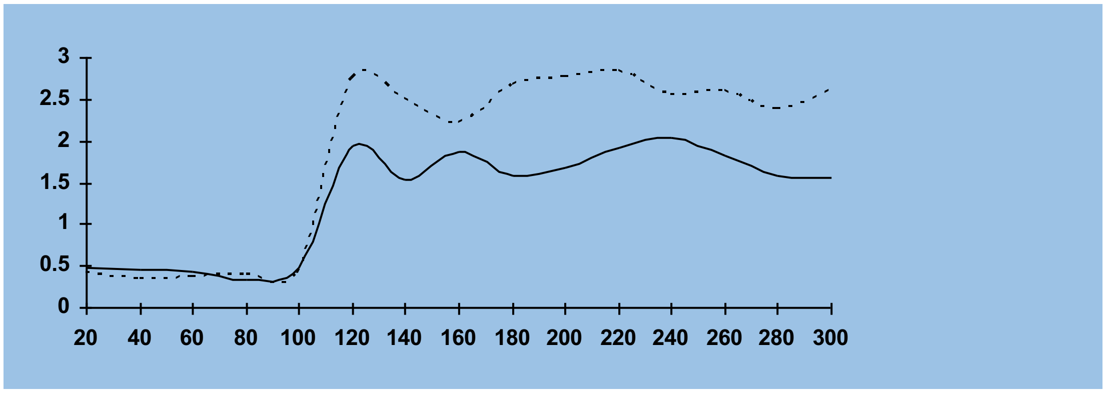

Fig. 3. Average packet transmission time over the network.

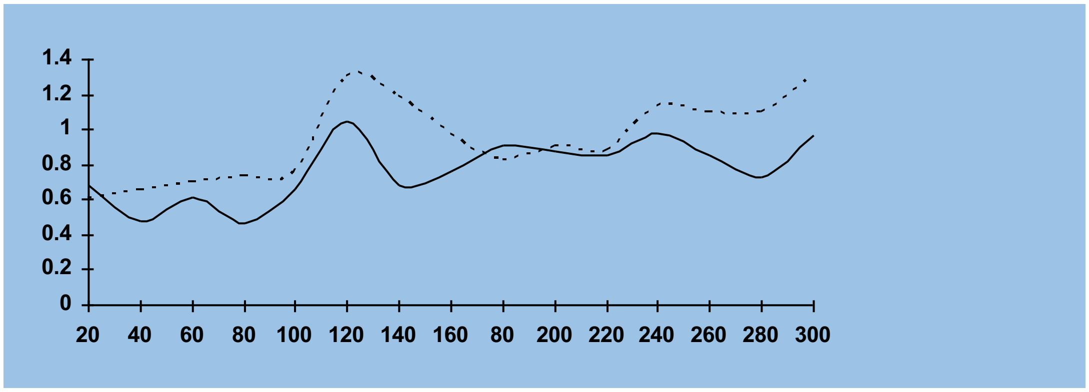

Fig. 4. The average transmission time of packets from node 6 to node 7 in the direction of 1-5.

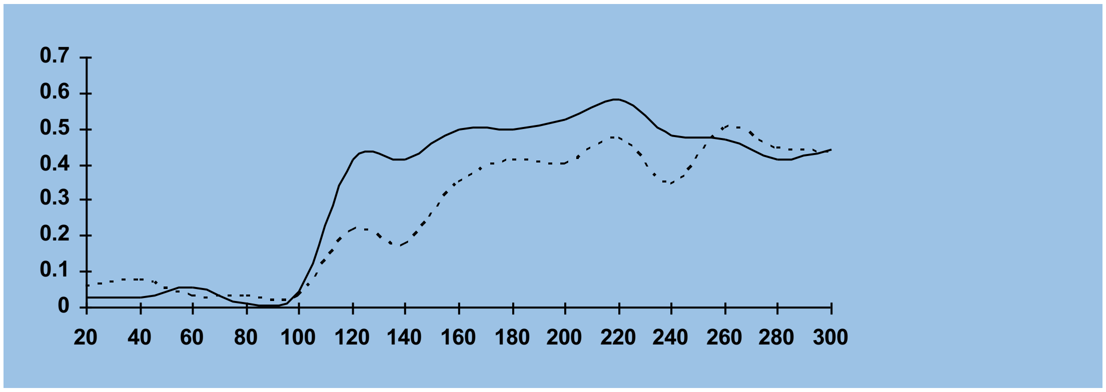

Fig. 5. Average loading of channel 1-2.

Conclusions

1. Considered the problem of flow control in communication networks.

It is shown that one of the most effective ways of operational flow control is adaptive routing.

2. A new decentralized algorithm of adaptive (dynamic) routing in communication networks with stream switching using the X.25 protocol is proposed.

3. Experimental studies of the proposed adaptive routing algorithm and its comparison with the static algorithm confirmed its high efficiency. For the simulated network with n = 15 nodes and m = 19 channels, the reduction in the average delivery time Tcp was 20–25%.

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