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Analysis of a Model for Improving the Efficiency of Routing Control in Data Transmission Networks Based on Fuzzy Logic

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Abstract: The article considers the principles and mechanisms of packet switching in data transmission networks based on virtual and datagram modes. The structure of the packet switching node and the description of the functioning of the block for receiving frames from the network path, the block for transmitting frames to the network path, the block for interaction with local subscribers and the routing block are given. The functional diagram of the router and the description of interface levels, network protocol and routing protocols are considered. The analysis of the traditional method of routing in a data transmission network with packet switching is carried out and the necessity of using intelligent adaptive technologies is substantiated. The possibility of applying the mathematical foundations of fuzzy logic in the process of routing packets in a data transmission network with packet switching is considered, the concepts of fuzzy and linguistic variables are given. An approach and a mechanism for estimating the route metric based on fuzzy logic are presented, its main input and output parameters are determined and analyzed. A model of a routing control system using a fuzzy logic apparatus has been developed to improve the efficiency of routing control in data transmission networks.

Keywords: Data Networks, Packet Switching, Routing, Metrics, Fuzzy Logic

1. Introduction

Modern data transmission networks (DTN) with packet switching (PS) are complicated and complex, the quality of functioning of which can most significantly affect the efficiency of the functioning of these networks. The possibilities for increasing the efficiency of DTN with PS are largely predetermined by their network topology, therefore, the issues of improving the efficiency of DTN with PS should be considered in conjunction with the topological structure of the network, methods and routing algorithms.

This allows us to formulate such a scientific problem as the development of a mathematical model of the functioning of the router, methods and routing algorithms that improve the efficiency of the functioning of DTN with PS.

2. Mechanisms and Principles of Packet Switching

Packet switching technology has been specifically designed to efficiently transport network applications that generate very uneven traffic with a high level of data rate ripple. When switching packets, all messages transmitted by the user are divided in the source node into relatively small parts, called packets [1]. The transmission of packets between the source of the message and the recipient is carried out in a virtual channel or the datagram mode [2-3].

Packet switching in virtual circuits (virtual circuit, or virtual channel) establishes a logical connection between the sending and transmitting device - a virtual channel. The transmitting device, having contacted the addressee, agrees with it the maximum message size and network route. Once a virtual channel is created, the two devices use it for the duration of the conversation. Each node in a logical route can perform switching and error checking.

The mechanism of virtual circuits creates stable paths for traffic in the network through the packet-switched network. This mechanism takes into account the existence of data flows in the network. If the goal is to lay a single path through the network for all packets of the flow, then a necessary (but not always the only) sign of such a flow should be the presence of all of its packets of common points of entry into the network and exit from the network.

For example, you might use one virtual circuit for real-time streaming and another for email traffic. In the latter case, different VCs will have different quality of Service (QoS) requirements and potentially be easier to satisfy than if the same VC carries traffic with different QoS requirements.

However, its purpose is the same everywhere - an intermediate node called a switch in these technologies, reads the label value from the incoming packet's header and looks through its switching table, which indicates which output port the incoming packet should be sent to. The switching table contains entries only about the virtual circuits passing through this switch, and not about all the nodes (or subnets, if the hierarchical addressing method is used) in the network.

Usually, in a large network, the number of virtual channels laid through a node is significantly less than the number of nodes and subnets, so the size of the switching table is much smaller than the size of the routing table, and, therefore, it takes much less time to look through it and does not require a lot of computing power from the switch.

In a packet-switched datagram network, each packet is addressed separately and treated as an independent entity with its control commands. Datagrams are usually called data packets, the sender and recipient addresses of which are not set by the network, but by the end user. Switching devices route each packet (datagram) independently, directing it through the network, and intermediate nodes determine the next route segment of the next packet.

The datagram method is effective for sending short messages. It does not require a cumbersome procedure for establishing a connection between subscribers. This method of data transmission is based on the fact that all transmitted packets are processed independently of each other, packet by packet. The decision on which node to send the incoming packet to is made based on a table containing a set of destination addresses and address information that uniquely identifies the next (transit or end) node. The term routing table is used as a generic name for these kinds of tables used for datagram transmission based only on the destination address of the end node.

Packets traveling to the same destination address can reach it in different ways due to changes in the state of the network, for example, the failure of intermediate routers. With the packet switching method, information intended to be transmitted to some object enters the transport layer in the form of a message, which is a message block. To transmit a message at lower levels, blocks are divided into small fragments, the maximum length of which is limited. For transmission over the channel, the packet is formed as a frame and enters the second link layer. Transferring a fragment between two terminal data equipment (DTE) consists of the following main operations performed by a data network [4-5]. In the terminal equipment of the source data, fragments are processed into a packet, a packet into a frame, and transmitted over a data channel to the nearest network switching node. In the switching node, the packet is extracted from the received frame to analyze its service part, the packet is packed into a frame and transferred to the next network switching node or to the recipient's data terminal equipment if it is connected to this node (Figure 1).

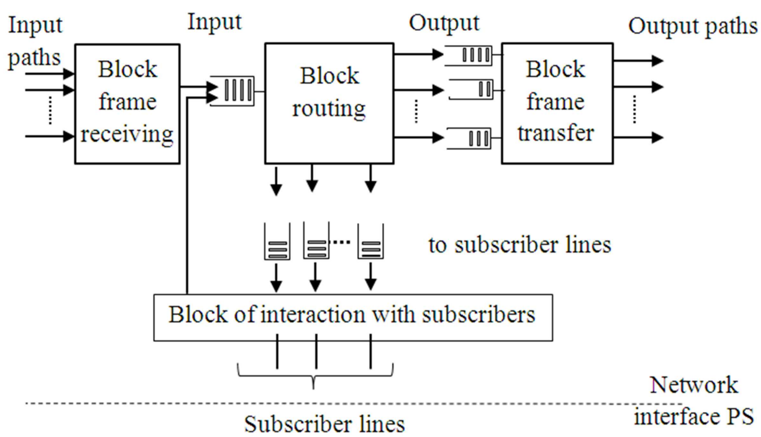

Figure 1. *Packet switching node structure.*

The receiver's DTE extracts the packet from the received frame and the message fragment from the packet. The packet-switching node consists of 4 main blocks:

1) block for receiving frames from the network path;
2) frame transmission block in the network path;
3) block of interaction with local subscribers;
4) routing block.

The block for receiving frames from the network path, connecting this node with neighboring nodes, after receiving the frames, analyzes the presence of errors in the frame, and if no errors are found, then the packet received in the frame is placed in the input queue to the routing block.

The routing block analyzes the destination address of the packet, selects, by the routing tables, the required output path or subscriber line to the local subscriber, and places the appropriate output queue in the packet. When the path is released (the end of the transmission of the previous packet), the frame transmission block selects the next packet from the queue, forms a frame on its basis (adding signs of the beginning and end of the frame, frame overhead, check characters) and transfers it to the path to the next node along the way to the destination. The block of interaction with local subscribers receives and transmits frames transmitted via local subscriber lines.

3. Generalized Description of the Functioning of the Router

A router is a device that collects information about the topology of interconnections and, based on it, forwards network layer packets to the destination network. The main function of the router is to read the headers of network protocol packets received and buffered on each port and decide on the further route of the packet to its network address, including the network number and host number. Router functions can be divided into 3 groups according to the layers of the OSI model (Figure 2) [6].

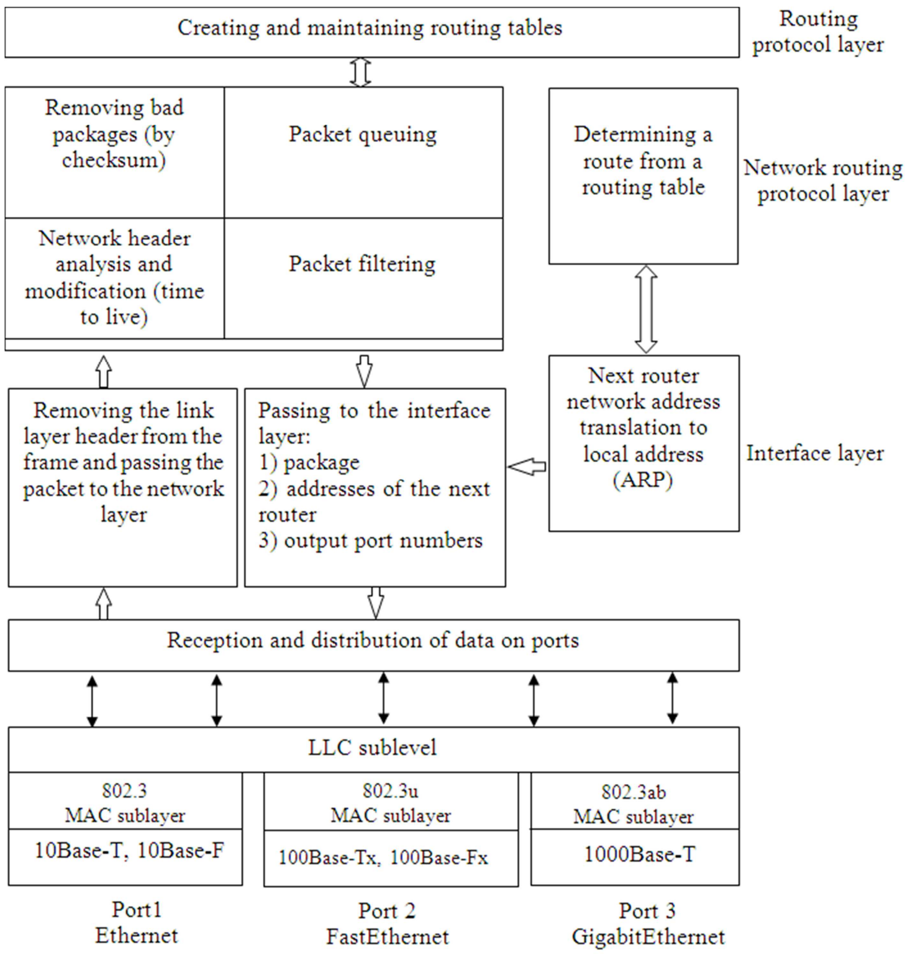

Figure 2. *Functional diagram of the router.*

3.1. Interface Level

Router interfaces perform a full set of physical and link layer functions for frame transmission, including accessing the medium, generating bit signals, receiving a frame, calculating the checksum, and transmitting the frame data field to the upper layer.

3.2. Network Protocol Layer

The network protocol extracts the network layer header from the packet and parses the contents of its fields. The checksum is checked, and if the packet arrived damaged, then it is discarded. The lifetime of the packet is checked, adjustments are made to the contents of some fields, and the checksum is recalculated.

At the network level, one of the most important functions of the router is performed - traffic filtering. The router allows you to set and process complex filtering rules. The network layer packet in the data field of a frame is represented by routers as an unstructured binary sequence. Routers, on the other hand, whose software contains a network protocol module, can parse and analyze individual fields of the packet.

They are equipped with advanced user interface tools that allow the administrator to set complex filtering rules.

The packets can form a queue if the packet arrival rate is higher than the processing rate here are various disciplines of packet service: first-in-first-out (FIFO) first-in-first-out (FIFO) random early detection when service is FIFO, but when the queue reaches a certain length, newly arriving packets are discarded, and as well as various priority service options.

The main function of a router is to determine the path of a packet. Based on the network number extracted from the packet header, the network protocol module finds a line in the routing table containing the network address of the next router and the port number to which the packet should be sent for it to move in the right direction. If there is no entry in the table for the packet's destination network, and, in addition, there is no entry for the default router, then the packet is discarded.

Before passing the network address of the next router to the link layer of the technology used in the network containing the next router. To do this, the network protocol refers to the address resolution protocol. Protocols of this type establish a correspondence between network and local addresses either based on predefined tables or by sending broadcast requests. The table of correspondence of local addresses to network addresses is built separately for each network interface. Address resolution protocols occupy an intermediate position between the network and link layers.

From the network layer, the packet, the next router's local address, and the router's port number are passed down to the link layer. Based on the specified port number, switching is performed with one of the router interfaces, using which the packet is packed into a frame of the appropriate format. The destination address field of the frame header is filled with the local address of the next router. The finished frame is sent to the network.

3.3. Routing Protocol Layer

Network protocols actively use the routing table in their work, but not by its construction. They don't do any maintenance. These functions are performed by routing protocols. Based on these protocols, routers exchange information about the network topology. And then they analyze the received information, determining the best routes according to certain criteria. The results of the analysis make up the contents of the routing tables.

4. Router Model Using the Fuzzy Logic Mechanism

It is known that one of the main tasks of the network layer is to solve the problem of routing, that is, to determine the path of data transmission from the sender node to the recipient node through intermediate nodes and then redirect the packet. Routing includes two main tasks [7]:

1) the task of constructing a route, i.e. determining effective routes;
2) the task of laying the route, i.e. transporting packets through the network.

The routing process is distributed and based on the use of routing tables, and each network node contains its table, which indicates all available directions in which a data packet can follow on its way to the destination node. The routing table contains the address of the destination network, the address of the next hop on the path to that network, and the route metric. The creation and subsequent updating of the table are carried out using protocols and their corresponding routing algorithms [8].

Since many different indicators are used in routing algorithms, complex algorithms when choosing a route can be based on this set of indicators, combining them in such a way that the result is one separate (integral) indicator - a metric.

A metric is a specific data structure that contains channel quality indicators as components. The following are the main indicators that are used to calculate the metric [9]:

1) available bandwidth on the data transmission path;
2) packet transmission delay on the route from the source node to the destination node;
3) reliability;
4) route length;
5) cost.

One of the main problems in solving the problem of routing in modern DTN is the need to take into account many factors: the workload of the buffer interfaces of devices, the free bandwidth of communication lines, reliability, the cost of communication, the number of intermediate relay systems on the route, and many others. Using multiple metrics allows for more accurate network modeling, but the problem of finding the right path can become very difficult.

One of the promising methods for solving the routing problem is the use of fuzzy logic. Routers of different models and manufacturers can have significant differences. Nevertheless, the presence of several interfaces (interface controllers) and buffer memory (for incoming and outgoing traffic) should be attributed to the general features of the structural model of the router.

It is known that each interface has two separate buffers for incoming and outgoing information flows, respectively. A packet arriving at one of the router's interfaces (input) must be redirected to some other interface (output) or discarded. The main task of routing is to select an output interface according to the packet's destination address.

The router model is represented by a set of queues and processing devices (Figure 3) and displays the packet transfer process implemented as follows [10]:

1) the incoming packet enters the queue;
2) the router processor, taking into account the service discipline, selects the packet and analyzes its header;
3) the processor determines the direction for message transmission, and maintains the relevance of routing tables by exchanging service packets with other nodes;
4) after processing the packet header and selecting the outgoing direction, the packet enters the waiting queue of the output channel.

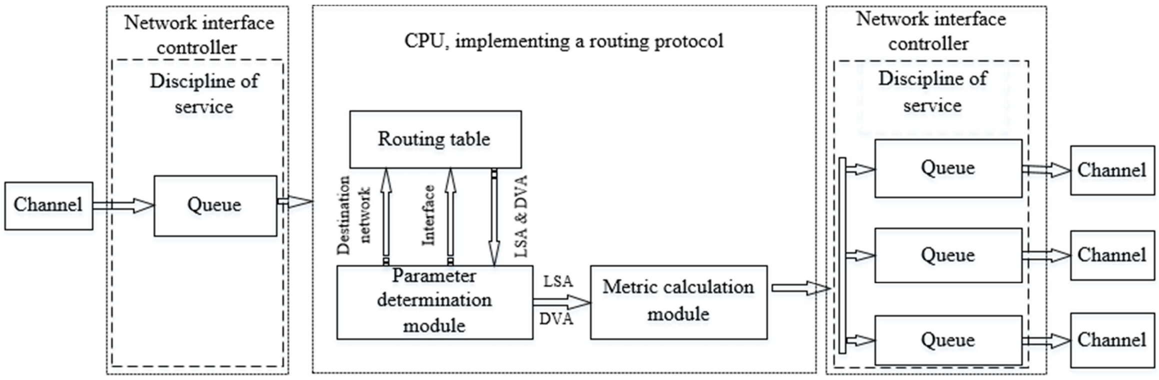

Figure 3. *Router model.*

The parameter determination module, based on the destination network address of the routed packet, queries the routing table and calculates the parameter values necessary to calculate the metric for a given output interface. Based on these parameters, the metric calculation module determines the value of the metric based on the underlying algorithm.

Consider the procedure for modeling a router using the RIP protocol as an example. The RIP protocol specification defines the range of metric values from 0 to 16 [11]. To improve the efficiency of the routing process based on the RIP protocol, we present the factors that affect the metric.

The main factor that has a great influence on the choice of route can be the degree of loading of the buffer memory of the egress interface, which determines the advisability of dropping the packet. In some cases, it is more appropriate to send the packet along a longer route, on which the buffers of the corresponding interfaces are less loaded. Thus, when routing, it would be reasonable to consider two input parameters: the distance and the load of the buffer memory of the corresponding interface. The degree of influence of each factor on the formation of a metric cannot be represented as a specific function or dependence, therefore, it is considered appropriate to form the solution to this problem based on fuzzy logic [12-16].

Since the answers to the questions of which factor to give preference to, distance or buffer load, and to what extent are largely subjective, it is advisable to form the decision selection algorithm based on fuzzy logic, which allows taking into account the influence of many factors associated with routing tasks. The proposed router model using the fuzzy logic mechanism is shown in Figure 4.

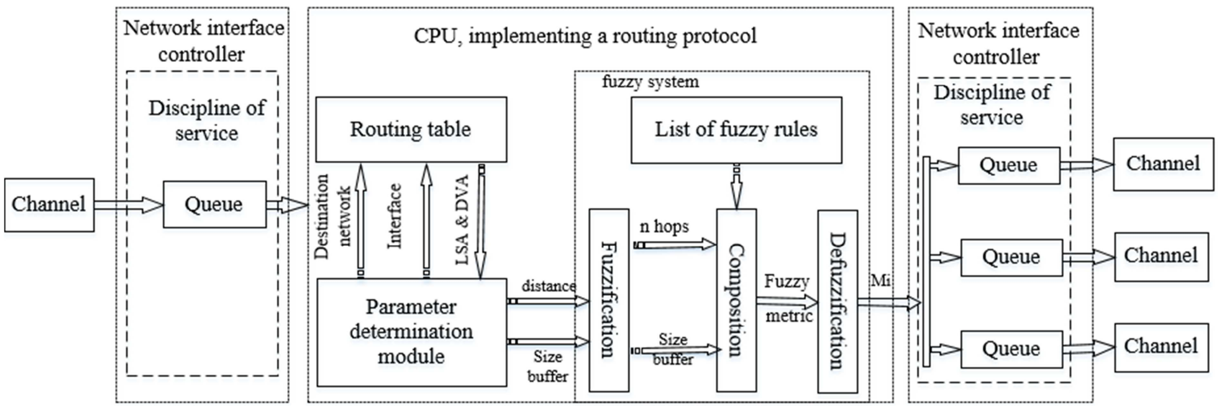

Figure 4. *Router model using the fuzzy logic mechanism.*

The metric calculation module takes on the character of a fuzzy system, and the process of determining the metric itself consists of the main stages of fuzzy response formation: fuzzification, composition, and defuzzification [17-18].

Fuzzification is associated with the definition of fuzzy sets that characterize the input variables - the distance and the utilization factor of the buffer memory Kmem. Such sets are described by characteristic functions that take values in the range from zero to one, which determine the degree of preference for the corresponding factor. In some cases, such functions can be determined objectively, based on the conditions of the problem, in others (which is most common) subjectively, based on common sense. The first stage of fuzzification consists of determining the input and output variables, as well as their corresponding fuzzy linguistic variables. At the second stage of fuzzification, for each linguistic variable, a set of terms and their corresponding fuzzy sets should be specified.

Composition. At the stage of composition, one should set the conditions of correspondence (rules) between the input and output fuzzy variables. The formation of such rules is carried out by an expert and is usually subjective. The structure of the rules is determined by the "if-then-else" format, and the semantics is determined by the knowledge and intuition of the expert. The list of fuzzy rules can be replenished and changed in the process of working out and debugging the decision-making algorithm.

Defuzzification. Based on the developed rules, the value of the corresponding "clear" variable is calculated. It is known that there are several defuzzification algorithms, and in this case, the Mamdani algorithm was used.

5. Conclusion

The analysis of the mechanisms, methods of packet switching, and block diagram of the packet switching node has been carried out. A generalized description of the functioning of the router is given. To solve the problem of determining the metric of the selected route, a routing model based on the apparatus of fuzzy logic has been developed. When forming the route metric, two parameters were used: "distance" and "output buffer load" with three terms for each linguistic variable.

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