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ALMATY
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POWER
ENGINEERING
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GUMARBEK DAUKEEV

Department of
Telecommunication
Networks and Systems

TRANSPORT TELECOMMUNICATION NETWORKS

Summary of lectures for students of specialty
5B071900 – Radio engineering, electronics and telecommunications

Almaty 2019

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Outlines of ten lectures on discipline "Transport telecommunication networks". They present the basics of building modern transport digital communication networks and methods for their description. Features of multiplexing are also given in the modern transport platforms.

Methodological guidelines are intended for students of all education forms of specialty 5B071900 – Radio engineering, Electronics and Telecommunications.

Il. 34, tab. 3, litr. – 15 names.

Reviewer: Kim Y.S. senior Lecturer, Master of technical Sciences

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Introduction

The discipline "Transport telecommunication networks" is a basic theoretical course for students of telecommunications universities. TTN is a means of transferring information by electronic means or it is a network of "electromagnetic wire and radio roads." This discipline is a generalization and development of the discipline "Digital transmission systems."

The purpose of studying the discipline "Transport telecommunication networks" (TTN) is to master the knowledge of the basic principles of building transport networks implemented on the basis of digital transmission systems (cable optical, radio); students mastering the essence of the phenomena occurring during the transmission of information, the principles of operation of technical devices, equipment and technologies PDH, SDH, ATM, WDM, NGSDH, PON, MPLS; the ability to correctly calculate, analyze and solve problems related to the digital transfer of information, the skills of operating the TTN.

The lectures examined the principles of building modern transport digital communication networks, methods for their description, digital methods of transmitting information.

As a result of studying the discipline, students should clearly understand the main directions and prospects for the development of transport telecommunication communication networks. To be able to apply the latest directions in the development of transport networks based on the OTN-OTH, Ethernet, T-MPLS, automatically switched networks (ASON / ASTN), etc.

Lecture №1. Introduction to modern transport telecommunication networks

Purpose of the lecture: to become familiar with the architecture of a modern telecommunication system.

Content:

- architecture of telecommunication systems;
- definition of the transmission system;
- principles of constructing equipment for optical transmission systems and transport networks.

The architecture of telecommunication systems.

Modern components for building telecommunication devices have a large range. Conventionally, they can be divided into electrical and electronic, optoelectronic, optical and software.

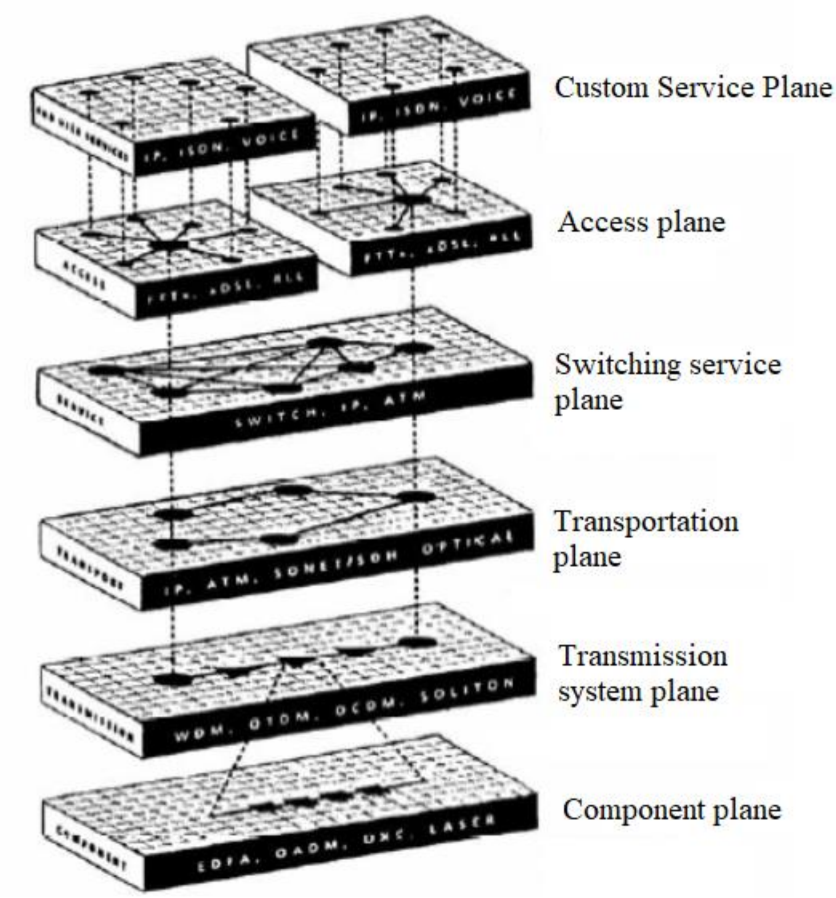

Figure 1.1 - The architecture of telecommunication systems

Electrical and electronic components include: metal cables and wires; transistors and integrated circuits (analog and digital) with varying degrees of integration; microprocessors; amplifiers; electrical signal regenerators and many others.

Optoelectronic and optical components and modules based on them have received especially widespread use over the past decade in the technology of telecommunications. The following product groups stand out among them: fiberglass optical fibers with the ability to transfer data at speeds from tens of gigabits per second to tens of terabits per second; Highly stable semiconductor and fiber lasers (LASER) included in transmitting optical modules; highly sensitive photodetectors that are part of the receiving optical modules; Erbium-doped fiber-optic amplifiers EDFA (Erbium Doped Fiber Amplifier); optical switches and routers OXC (Optical Cross-Connect); multiplexers and demultiplexers of wave and time optical signals OADM (Optical Add-Drop Multiplexers); compensators of distortions of optical signals caused by chromatic and polarization mode dispersions; optical processors based on photonic crystals.

Software components and modules are algorithmic software for electrical and optical devices that implement serial or parallel signal processing procedures, for example, digital filtering, cross switching (switching), phase alignment of digital data during multiplexing, control functions, etc.

In the plane of transmission systems, analog systems with frequency multiplexing of channels, typical group paths, electric and radio-relay linear paths can be considered.

Transmission systems are equipped with means of effective control, management, reservation of transmission areas. In the structure of transmission systems, terminal and intermediate stations are distinguished, which are combined in the transmission sections: regeneration, amplification, multiplexing. Transmission systems are an integral part of the transport communication network, which is represented by a separate plane.

The transportation plane provides for well-developed solutions for the automated creation, commissioning, monitoring and protection of paths and sections with physical and virtual channels, the creation of routing tables for paths and channels, their monitoring and control.

It is the plane of switching services that is the basis for the creation of intelligent networks, databases of services and their technical and economic availability for users. The functioning of switching nodes determines the load (traffic) for transport networks and their corresponding development.

The flatness of user services reflects all known and popular telecommunication services, which include: circuit-switched telephony and IP-telephony (Voice), video communication, video conferencing, the Internet, e-mail, sound broadcasting, digital television, television travel, etc.

Definition of a transmission system.

For completeness of the terms used below are a number of definitions.

A network node is a complex of technical means that provides the connection of network stations of the primary network, the formation and redistribution of network paths, typical transmission channels and typical physical circuits, as well as providing them to secondary networks.

Network station - a complex of technical means that provides the formation and provision of secondary physical networks of typical physical circuits, typical transmission channels and network paths, as well as their transit.

A transport network is generally understood as a combination of resources of transmission systems (channels, paths, sections, or transmission sections), their means of control, operational switching, backup, and control, designed to transfer information between specified points. An integral part of the transport network are synchronization and control networks, the definitions of which are also given below.

The synchronization network is formed by a combination of clock generators that interact in a specific order, distribution systems of clock signals and the clock itself.

Control network is a special network that provides control of the telecommunication network and its services by organizing interconnection with the components of the telecommunication network (network stations and network nodes) based on common interfaces and protocols standardized by ITU-T and other organizations.

Generalized scheme of the optical transmission system

Figure 1.2 shows a generalized diagram of an optical transmission system in which the blocks display possible types of equipment for transmission systems.

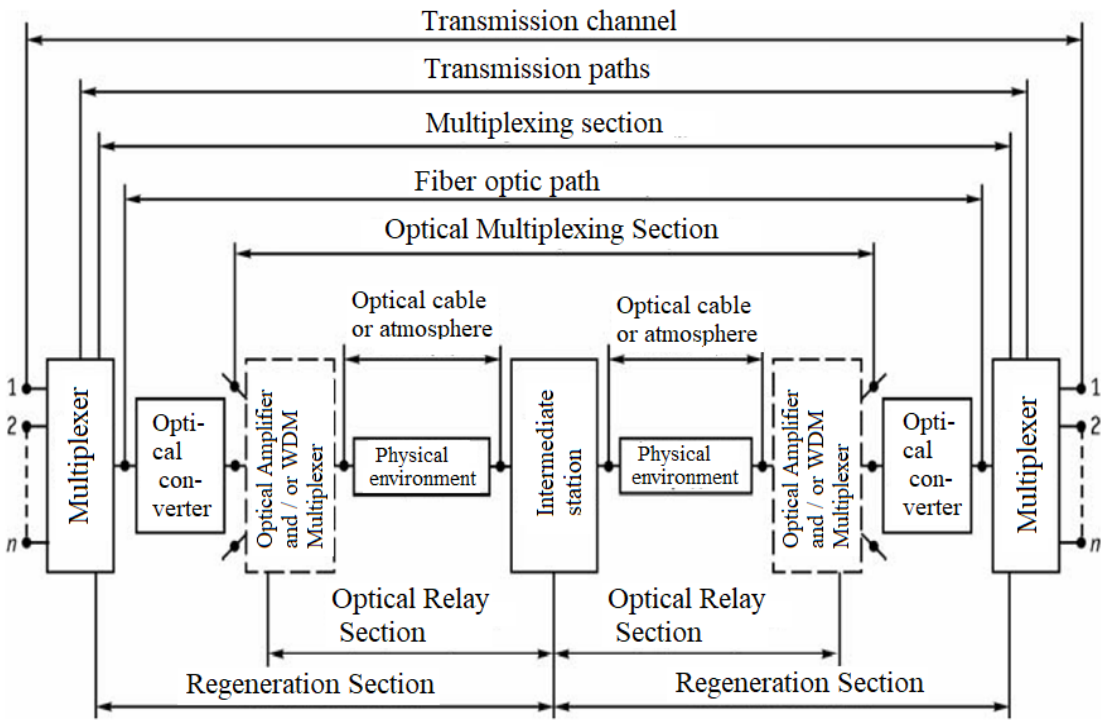

Figure 1.2 - Generalized diagram of the optical transmission system

Principles of constructing equipment for optical transmission systems and transport networks

The general structure of the equipment (for example, SDH equipment) of transport networks is presented in figure 1.3. This structure provides for:

- aggregate (linear) interfaces in which the characteristics of optical transmitters and receivers are determined;
- TU and AU pointer tuning functions, multiplexing / demultiplexing of standard blocks in TUG, AUG and STM-N for SDH equipment;
- cross components (matrix of switching digital signals, optical switch of wave channels and optical packets) for switching electrical and optical paths with the aim of realizing transit in nodes, isolating and inputting digital streams and wave channels, protective switching in connections and etc .;
- channel (user) interfaces provided for loading / unloading digital data to various users of the transport network (electronic telephone exchanges, Ethernet switches, etc.);
- local and network management with support for the functions of the F (RS-232) and Q (G.773) interfaces, control data transmission channels and protocol ¬ fillings;
- clock network synchronization with the ability to program priorities for selecting clock signals and input ports, for example, TK port, or linear ports, or component ports E1, as well as outputting the clock signal to port T4;
- service alarms for light and sound indication of abnormal conditions in the equipment basket, on a stand, in a row, etc .;
- power supply of the equipment, carried out from sources of supply voltages 48 V and 60 V.

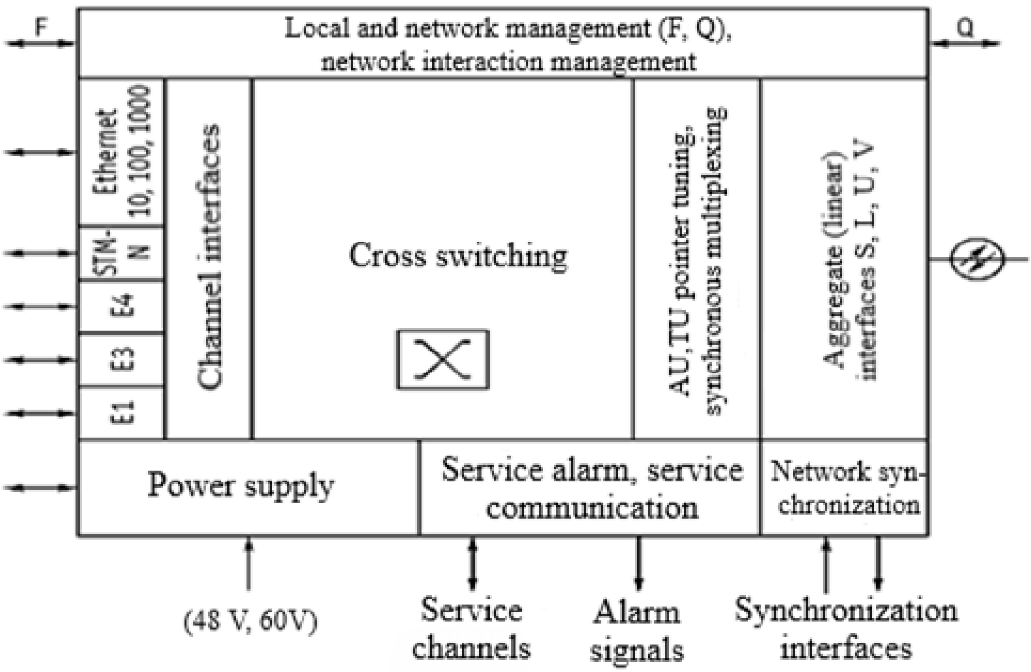

Figure 1.3 - The general structure of the equipment of transport networks

Lecture №2. Optical Transport Network Model Features

The purpose of the lecture: the study of the model of transport networks.
Content:
- SDH transport network model;
- ATM transport network model;
- OTN-OTH transport network model;
- Ethernet transport network model.

Given the dynamic growth of information transfer requirements, increasing requirements for transmission quality, security and controllability of connections, ITU-T develops and improves standards for information transfer in optical systems. One of the main directions of ITU-T's activity was the adoption of the concept of building transport networks, published in the form of G.805 Recommendation, and the development of models of transport networks based on fiber optic and radio relay transmission systems. In this case, the main role is given to fiber-optic systems. Description of transport networks models, multiplexing technological schemes, interfaces, equipment, control, synchronization, etc. given in a large ITU-T package of G, Y, I, X series, etc.

Currently, transport networks are being built in accordance to the models (figure 2.1).

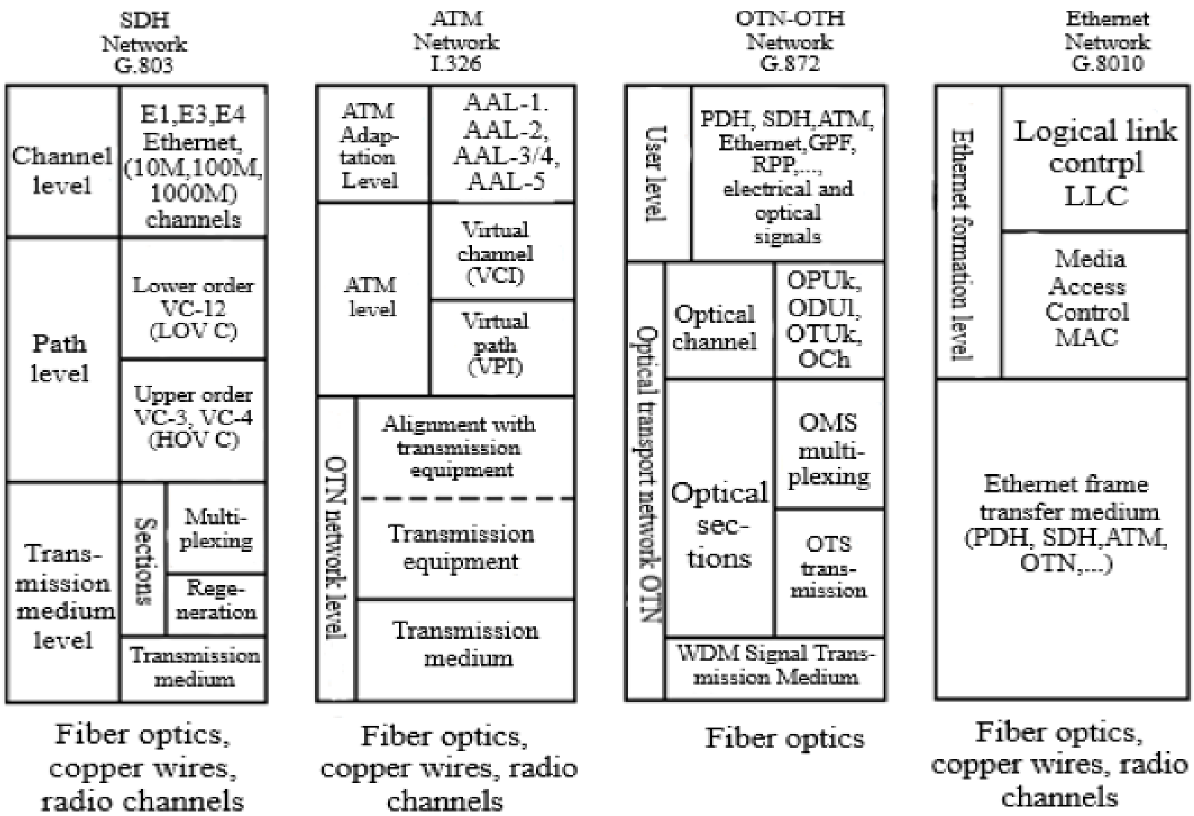

Figure 2.1 - Transport communication network models defined by ITU-T

These recommendations are used by equipment manufacturers and network operators in the design, launch and operation of transport networks.

SDH transport network model.

The SDH transport network model is represented by three levels independent of their organization: transmission media, paths (information transmission routes), channels.

The level of the transmission medium is mainly based on fiber optic lines (transmission medium), in which sections for regenerating digital linear signals and sections for multiplexing digital data are created. The transmission medium contains: fiber optical fibers in various cable designs; electro-optical converters on the transmission and optoelectronic converters on the reception; optical amplifiers, optical attenuators and dispersion compensators; detachable and one-piece optical connectors; linear encoders and decoders; optical modulators and optical detectors.

The SDH network path level is subdivided into two sublevels - high and low - standardly indicated in the technical literature: HOVC (Higher Order Virtual Container) - a top-level virtual container, and LOVC (Lower Order Virtual Container) - a lower-level virtual container. Virtual containers of high and low levels are cyclic digital capacities provided for loading information data with suitable speeds. Low-level virtual containers can be combined to fit into high-level virtual containers.

The SDH network link layer provides interfaces for transport network users. Considering that the SDH transport network is part of the primary communication network, at the channel level, coordination is made with secondary networks (users), for example, telephone networks through digital data streams 2.048 Mbit / s (E1), with Ethernet networks at speeds 10, 100 and 1000 Mb / s transmissions through virtual container hookups and negotiation protocols.

ATM transport network model.

The model of the ATM transport network is represented by three levels independent in their organization: transmission medium, asynchronous transmission mode, ATM adaptation.

The transmission medium level in the ATM transport network model can be implemented, according to ATM standards, by any transmission system, for example, systems with plesiochronous multiplexing (PDH) or synchronous multiplexing (SDH) systems. In this case, any medium and transmission equipment may be used (copper wires with xDSL modems, radio channels with corresponding radio frequency converters, atmospheric optical channels with appropriate means of coupling, fiber-optic systems).

The ATM layer is divided into sublevels of the virtual channel and virtual path. These ATM-level entities are associated with data presentation units called cells and having a capacity of 53 bytes. This capacity is divided into a header field 5 bytes long and a load field (user segment) 48 bytes long.

The ATM adaptation layer acts as an interface between the ATM transport network with its virtual connections and users of transport services (secondary communication networks), for example, telephone networks, the Internet, local

Ethernet networks, etc. At the same time, various types of traffic are identified by various types of AAL level adaptation (ATM Adaptation Level, AAL-1, AAL-2, AAL-3/4, AAL-5), which provide for the formation of segments with different structure for the user load.

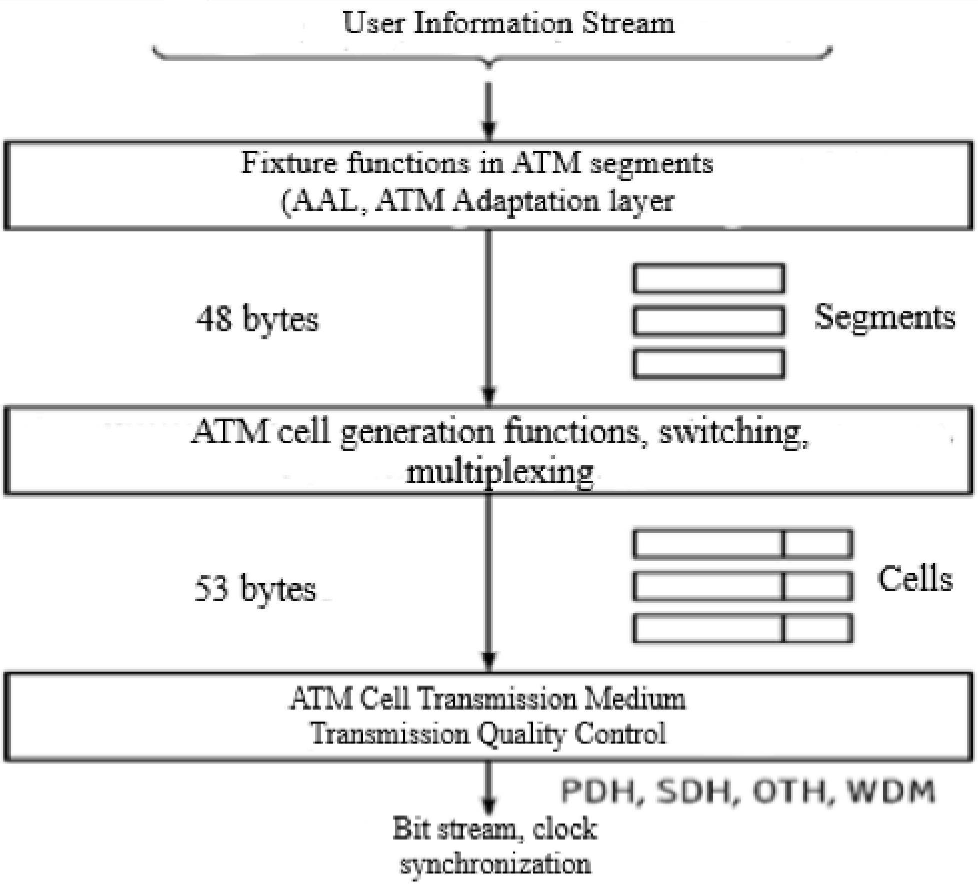

Figure 2.2 - The Formation of the flow of cells of the transport network ATM

OTN-OTH transport network model.

The OTN-OTH transport network model is represented by two levels independent in their organization: the OTN network and the user.

The OTN network layer consists of three physically and logically connected sublevels: a wavelength separation medium (WDM); optical sections of relay OTS (Optical Transmission Section) and multiplexing OMS (Optical Multiplex Section); optical channels OCh (Optical Channel) with a load in the form of optical transport blocks OTUk (Optical Transport Unit-k) with the inclusion of data blocks of optical channels ODUk (Optical channel Data Unit-k), which, in turn, include blocks payload of optical channels OPUk (Optical Channel Payload Unit-k). Index k corresponds to the hierarchical stage of OTN (k - 1,2,3) and indicates cycles with different durations, capacities and transfer rates.

The user level of the optical transport network OTN-OTH acts as an interface between the transport network and the networks of users of transport services, which include SDH, ATM, Ethernet, etc.

Ethernet transport network model.

The Ethernet transport network model consists of two levels: the medium level of Ethernet frame transmission and Ethernet frame formation (packets).

The level of the Ethernet network transmission medium can be implemented on the basis of copper wires, optical fibers, radio channels and atmospheric optical channels using the appropriate signal converters (transceivers), which is typical for local and city communication networks, and this is the most economical solution relative to other models of transport networks.

The level of formation of Ethernet frames (packets) consists of two sublevels: LLC logical channel control (Logical Link Control) and access control to the transmission medium MAC (Medium Access Control). These sublevels are protocol, i.e. their functions are prescribed by certain algorithms for processors that form frames with information data and service messages.

The logical development of the Ethernet transport network model was the model of the transport network with packet transmission and label switching T-MPLS (Transport Multi-Protocol Label Switching - transport multi-protocol label switching). The solutions for this technology are presented by a number of ITU-T recommendations:

- G.8110 - MPLS network layer architecture;
- G.8110.1 — application of MPLS in a transport network;
- G.8112 - the interface between the nodes of the MPLS network;
- G.8121 - MPLS equipment functions;
- Y.1720 (G.8131) - protective switching in the MPLS network;
- Y.17H — MPLS network maintenance and operation mechanisms.

The development of this model is aimed at increasing the efficiency of using the resources of backbone and intrazonal optical transport networks with cyclic digital transmission technologies: PDH, SDH and OTN. In addition, for local and local networks where the use of Ethernet transmission prevails at speeds of 100, 1000 and 10000 Mbps, the use of the T-MPLS protocol will allow the introduction of a wide range of voice services (IP-telephony), video image (IPTV-TV), Internet, etc. The structure and its corresponding T-MPLS interfaces are discussed in the next chapter.

Lecture №3. Synchronous Digital Hierarchy (SDH) Transmission Systems

The purpose of the lecture: the study of the main features of the synchronous digital hierarchy (SDH).

Content:

- structure of the synchronous transport module STM-1;
- formation of the STM-16 module;
- placement of containers in the STM-1 module.

The structure of the synchronous transport module STM.

The SDH Digital Hierarchy is a method of multiplexing various digital data into a single unit, called the Synchronous Transport Module (STM), with the goal of transmitting this module over a communications link. A simplified STM structure is shown in Figure 3.1.

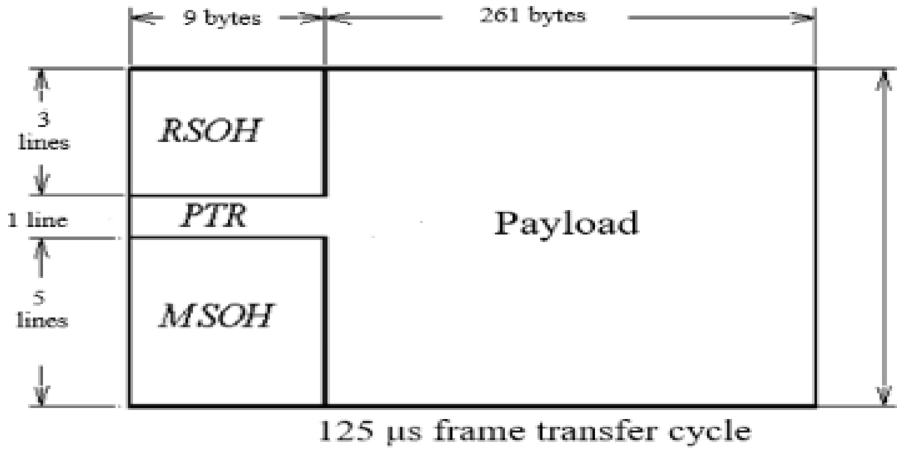

Figure 3.1 - Structure of the synchronous transport module STM-1

The module is a frame (frame) 9 · 270 = 2430 bytes. In addition to the transmitted information (referred to in the literature as a payload), it contains in the 4th line a pointer (Pointer, PTR) that defines the beginning of the recording of the payload. To determine the route of the transport module, a Section Over Head (SOH) is written on the left side of the frame. The lower 5 · 9 = 45 bytes (after the pointer) are responsible for the delivery of information to that place in the network, to the multiplexer where this transport module will be re-formed. This part of the header is called: sectional header of the multiplexer (MSOH). The upper 3 · 9 = 27 bytes (up to the pointer) represent the sectional header of the regenerator (RSOH), where the restoration of the stream “damaged” by noise and correction of errors in it will be carried out.

One transmission cycle includes reading in line such a rectangular table. The byte order is from left to right, from top to bottom (the same as when reading text on a page). The STM-1 transmission cycle time is 125 µs, i.e. it is repeated at a frequency of 8 kHz. Each cell corresponds to a transmission speed of 8 bits · 8 kHz = 64 kbit / s. So, if you spend 125 µs on the transfer of each rectangular frame to the line, then 9 · 270 · 64 kbit / s = 155520 Kbit / s, that is, 155 Mbps.

Table 3.1 - Synchronous Digital Hierarchy

Hierarchy level	Type of synchronous transport module	Bit rate, Mbps
1	STM-1	155,520
2	STM-4	622,080
3	STM-16	2488,320
4	STM-64	9953,280

To create more powerful digital streams in SDH systems, the following speed hierarchy is formed (table 3.1): 4 STM-1 modules are combined by byte multiplexing into the STM-4 module, transmitted at a speed of 622.080 Mbit / s; then 4 STM-4 modules are combined into an STM-16 module with a transfer rate of 2488.320 Mbps; finally 4 STM-16 modules can be combined into a high-speed STM-64 module (9953,280 Mb / s).

Formation of the STM-16 module.

Figure 3.2 shows the formation of the STM-16 module. First, every 4 STM-1 modules are combined using four-input multiplexers into an STM-4 module, then four STM-4 modules are multiplexed by the same four-input multiplexer into an STM-16 module. However, there is a 16-input multiplexer with which you can simultaneously combine 16 STM-1 modules into one STM-16 module.

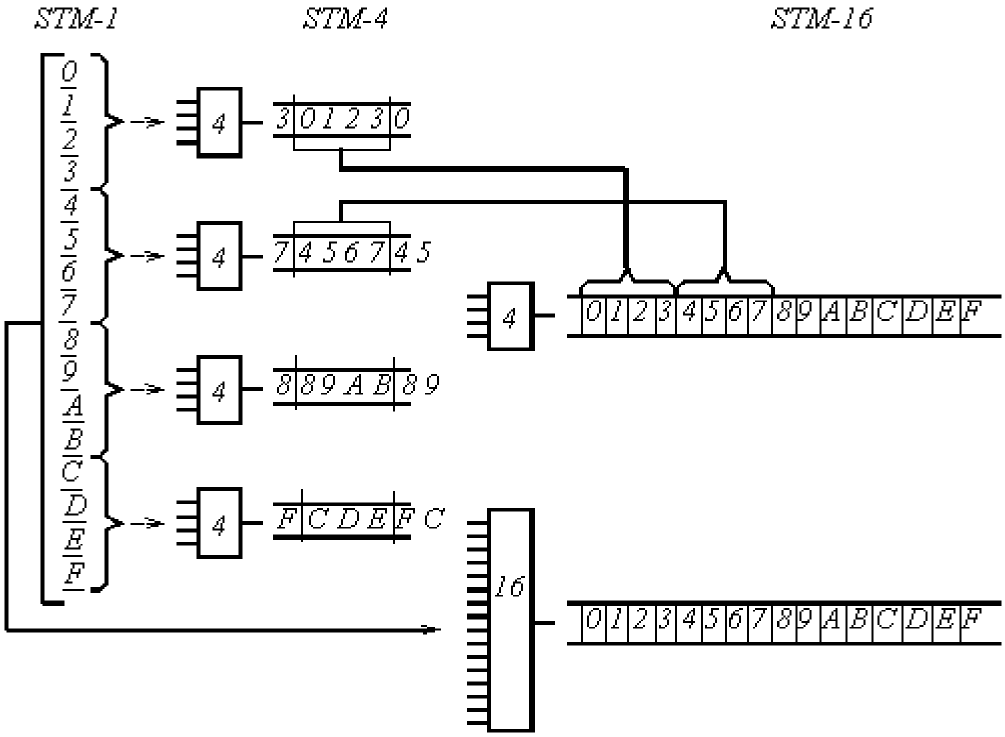

Figure 3.2 - Formation of a synchronous transport module STM – 16

Placement of containers in the STM-1 module.

Formation of the STM-1 module. The SDH network applies container shipping principles. Signals to be transported are preliminarily placed in standard containers (Container - C). All operations with containers are carried out regardless of their contents, which ensures the transparency of the SDH network, i.e. ability to transport various signals, in particular PDH signals. The closest speed to the first level of the SDH hierarchy (155.520 Mbit / s) is the digital stream with a speed of 139.264 Mbit / s, formed at the output of the equipment of the plesiochronous digital hierarchy IKM-1920. It is easiest to place in the STM-1 module. To do this, the incoming digital signal is first “packed” in a container (ie, placed at certain positions of its cycle), which is designated C-4. The C-4 container frame contains 9 rows and 260 single-byte columns. By adding another column on the left - a route or path header (Path Over Head - RON) - this container is transformed into a virtual container VC-4.

Finally, to place the VC-4 virtual container in the STM-1 module, it is provided with a pointer (PTR), thus forming the administrative unit AU-4 (Administrative Unit), and the latter is placed directly in the STM-1 module along with the section header SOH.

The synchronous transport module STM-1 can also be loaded with plesiochronous streams with speeds of 2.048 Mbit / s. Such flows are formed by the PCM-30 apparatus; they are widespread in modern networks. For the initial "packaging" container C12 is used. A digital signal is placed at certain positions of this container. By adding a route, or transport, header (RON), a virtual container VC-12 is formed. Virtual containers are formed and disbanded at the points at the ends of the paths.

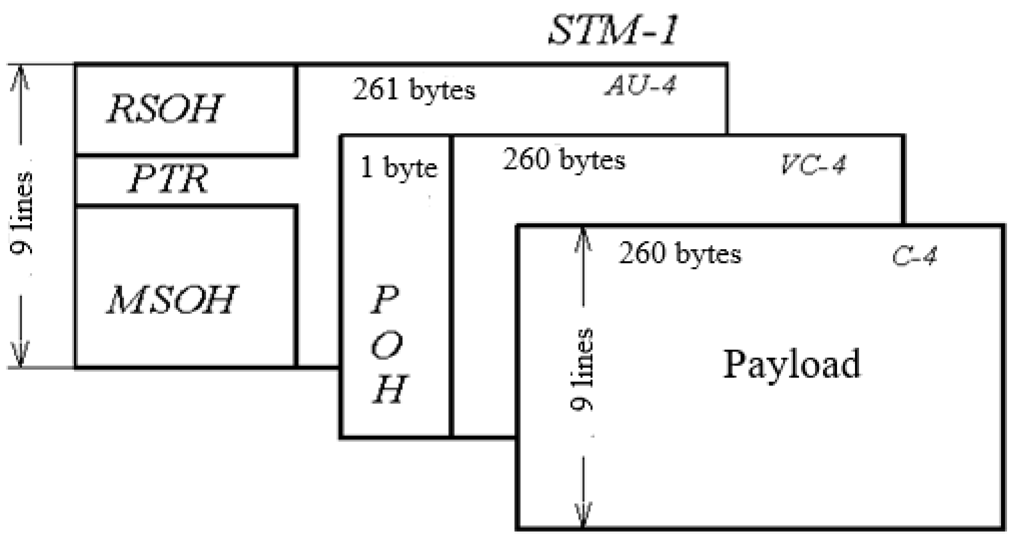

Figure 3.3 - Placement of containers in the STM-1 module

The STM-1 module can accommodate 63 VC-12 virtual containers. In doing so, proceed as follows. The virtual container VC-12 is provided with a pointer (PTR) and there by form the transport unit TU-12 (Tributary Unit). Now the digital streams of different transport blocks can be combined into a digital stream 155.520 Mbit / s. First, three TU-12 transport blocks are multiplexed into a TUG-2 transport block group (Tributary Unit Group), then seven TUG-2 groups are multiplexed into TUG-3 transport block groups, and three TUG-3 groups are combined together and placed in a virtual container VC-4. Further, the transformation path is known.

Lecture №3. SDH multiplexing scheme and basic elements

The purpose of the lecture: the study of the multiplexing scheme SONET / SDH and basic elements.

Content:

- placement in STM-N;

- block diagram of the multiplexer;
- block diagram of the multiplexer as an example.

Figure 4.1 also shows the way of placing in STM-N, N = 1,4,16 different digital streams from the equipment of the plesiochronous digital hierarchy. Plesiochronous digital streams of all levels are placed in containers C using the speed equalization procedure (positive, negative and two-way). The presence of a large number of pointers (PTR) allows you to clearly determine the location in the STM-N module of any digital stream with speeds of 2,048; 34.368 and 139.264 Mbps. Commercially available Add / Drop Multiplexer (ADM) multiplexers allow you to branch and add any digital streams.

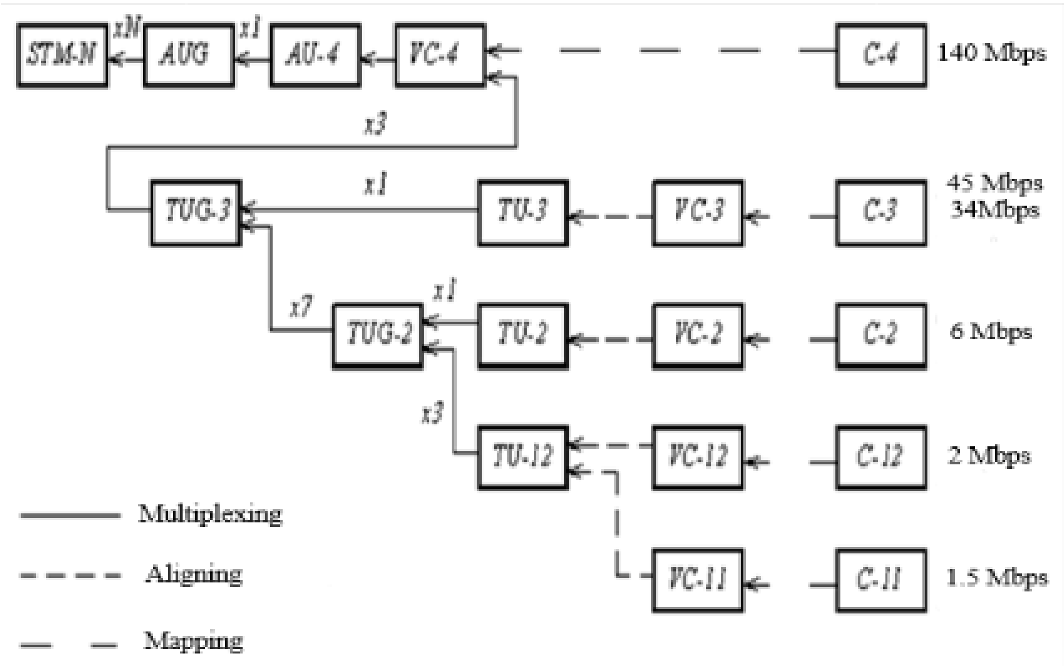

Figure 4.1 - Entering plesiochronous digital streams into the synchronous transport module STM-N

An important feature of the SDH equipment is that, in addition to routing information, in path and network headers, a lot of information is created that allows monitoring and control of the entire network as a whole, performing remote switching in multiplexers at the request of customers, monitoring and diagnostics, and detecting and eliminating them in a timely manner malfunctions, implement efficient network operation and maintain the high quality of the services provided.

The main difference between the SDH system and the PDH system is the transition to a new principle of multiplexing. In the SDH system, synchronous multiplexing / demultiplexing is performed, which allows direct access to the PDH channels that are transmitted on the SDH network.

An important feature of the SDH equipment is that in addition to the routing information, a lot of information is created in the path and network headers, which allows monitoring and control of the entire network as a whole, performing remote switching in multiplexers at the request of customers, monitoring and diagnostics, and timely troubleshooting and troubleshooting. implement efficient network operation and maintain the high quality of services provided.

The PDH and SDH hierarchies interact through the multiplexing and demultiplexing of PDH streams into SDH systems. The main difference between the SDH system and the PDH system is the transition to a new principle of multiplexing. In the SDH system, synchronous multiplexing / demultiplexing is performed, which allows direct access to the PDH channels that are transmitted on the SDH network. This rather important and simple innovation in technology has led to the fact that in general the multiplexing technology in the SDH network is much more complicated than the technology in the PDH network, the requirements for synchronization and quality parameters of the transmission medium and transmission system have been strengthened, and the number of parameters that are essential for network operation.

Block diagram of the multiplexer.

The structural scheme of the multiplexer is determined primarily by its configuration, which, in turn, depends on the specific network tasks performed by this multiplexer. In addition, the structural diagram is determined by the elemental base, technology and production features. The multiplexer design and the manufacturer's traditions also play a role in the formation of the structural diagram.

The most widely used are modular designs of multiplexers, which allow changing the set of plug-in modules to change the configuration of the multiplexer in accordance to specific tasks and, most importantly, increase its capabilities as the network develops. It should be noted that modular multiplexers, with their obvious technical advantages, are relatively expensive, so “mini” multiplexers are also widely used. The latter hase an unchanged configuration and a minimum of functions, for example, the function of connecting paths (cross-connection) is excluded from them, the possibilities of redundancy are reduced, and so on.

Let us consider the block diagram of a multiplexer using the example of a fourth-level modular multiplexer of a synchronous digital hierarchy (forming synchronous STM-4 modules). This diagram is shown in figure 4.2.

This unit implements the functions of connecting paths of high and low levels of NRS-n and LPC-m. Signals are sent to the SM unit in the format of virtual containers VC-4, temporary switching of signals is carried out at the levels of VC-11, VC-12, VC-3 and VC-4 and is divided between transmission mains and access flows. In multiplexers of the fourth level, the capabilities of the switching unit are usually equivalent to 24 STM-1 streams (63 x 24 = 1512 streams 2 Mbit / s). Since the SM block is one of the most complex, whenever possible it is replaced by simpler ones. So, in the configuration of the regenerator, instead of the switching unit, a unit is installed that provides a simple connection between two linear units. In the configuration of the terminal (terminal) multiplexer, the switching unit can be replaced by a much simpler one, which provides the connection of the main and access signals without the function of their switching. However, the SM unit, in addition, often performs the functions of protecting the line and transmission path.

Four interface groups (IG A, B, C, D) are adjacent to the switching blocks. Two of them (IG A and IG B) are usually equipped with interface blocks of synchronous flows, and two (IG C and IG D) are used to connect the interface blocks of access signals. In particular, figure 4.2 shows that group A contains two STM-4 interface units (one main, one redundant, 1 + 1 type redundancy), group B contains four STM optical (or electrical) interface units -1, combined in pairs (one primary, another backup, redundancy is also of type 1 + 1), group C - four interface blocks of streams 2 Mbit / s, and group D - five blocks of streams 140 Mbit / s. Each interface block of 2 Mbps streams has 21 ports for connecting access channels; these blocks are reserved in the ratio of 3: 1 (one reserve for three workers). In the event of a failure of one of the operating units, the corresponding access channels are switched to the backup using the switching board to the backup PR. Similarly, each of the four 140 Mbps access channels can also be switched to a standby unit (4: 1 standby).

The following signal conversions are carried out in the STM-4 interface blocks on the transmission:

- the signals of the loading units TU-12, TU-3 coming from the switching unit are embedded in the VC-4 virtual containers, to which the PTR pointers are added (AU-4 administrative units are formed);
- to the four AU-4 blocks obtained as a result of the conversion of the load blocks or received from the switching unit, sectional subheadings MSOH and RSOH are added (four STM-1 signals are generated);
- four STM-1 signals are multiplexed into an STM-4 signal;
- the electrical signal STM-4 is scrambled, converted to optical and fed to the output connector of the STM-4 unit.

At the reception:

- the optical signal STM-4 is converted into electrical and is damped;
- the STM-4 signal is demultiplexed into four STM-1 signals;
- RSOH and MSOH are deleted, the PTR AU pointer is processed;
- AU-4 signals are transmitted to the switching unit or converted into a VC-4 signal;
- TU-12 and TU-3 signals are extracted from the VC-4 signal and transmitted to the switching unit.

Similarly, STM-1 signals are processed in STM-1 interface units.

The signals of the access stream 140 Mbit / s (139264 kbit / s) in the interface block on the transfer are converted from the CMI code to the NRZ code, the fixed insert bits and the service bits and the path header RON are added to it. Thus, the access stream signals are converted to VC-4 signals. Further conversion is similar to conversions in the STM-1 block. On the transfer, inverse transformations are performed.

The interface block of 2 Mbit / s access streams (2048 kbit / s) on the transmission converts 21 incoming 2 Mbit / s stream from HDB3 code to NRZ code. Further, according to the type of input (asynchronous, bit-synchronous, or other), 21 VC-12 virtual container streams are formed, which are sequentially converted into seven TUG-2 signals and then into one TUG-3 signal. The TUG-3 signal is transmitted to the switching unit. At the reception, reverse transformations are carried out.

At the bottom of the block diagram of the multiplexer in figure 4.2 three more blocks are shown: control, generator and access to headers.

The control unit (system controller) controls the equipment.

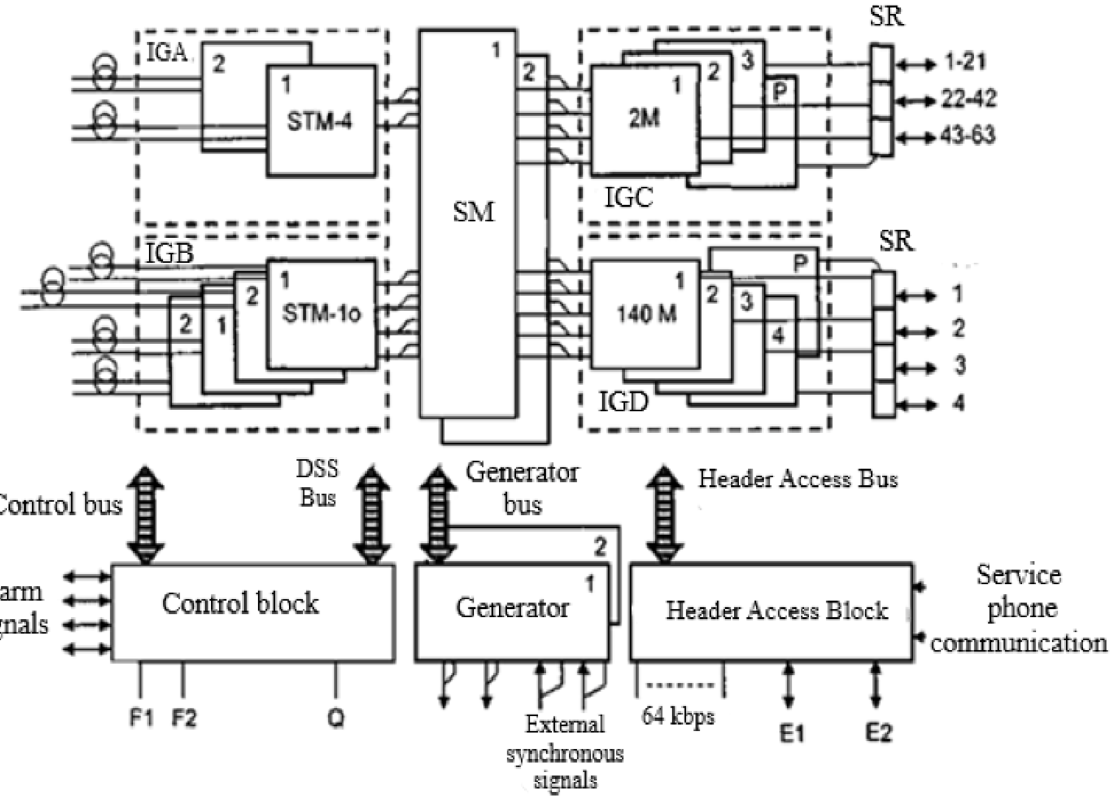

Figure 4.2 - Block diagram of a modular synchronous multiplexer

Lecture №5. Passive Optical Networks (PON)

The purpose of the lecture: the study of passive optical networks (PON).

Content:

- the history of the emergence of PON technology;
- technology topology of passive optical network PON.

The development of the Internet, including the emergence of new communication services, contributes to the growth of data flows transmitted over the network and forces operators to look for ways to increase the throughput of transport networks. When choosing a solution, you must consider:

- the variety of needs of subscribers; - potential for network development.

Passive optical network technology PON (passive optical network) is a PON access distribution network based on a tree-like fiber cable architecture with passive optical couplers on the nodes, which seems to be the most economical and capable of providing broadband transmission of various applications. At the same time, the PON architecture has the necessary efficiency of expanding both network nodes and bandwidth, depending on the present and future needs of subscribers.

Topology of technology of passive optical networks PON.

The following topologies of optical access networks can be distinguished: point-to-point, ring, tree with active nodes, tree with passive optical elements.

The simplest architecture. The main disadvantage is associated with the low efficiency of cable systems. It is necessary to maintain a separate wok from the central office to each building or to each corporate subscriber. This approach can be implemented when the subscriber unit (building, office, enterprise) to which a dedicated cable line is being laid can use these lines cost-effectively. The P2P topology does not impose restrictions on the network technology used. P2P can be implemented for any network standard, as well as for non-standard solutions, for example, for optical modems. From the point of view of security and protection of the transmitted information, a P2P connection provides maximum security for subscriber nodes. Since OK needs to be laid individually for each subscriber, this approach is the most expensive, and it is attractive mainly for large corporate clients.

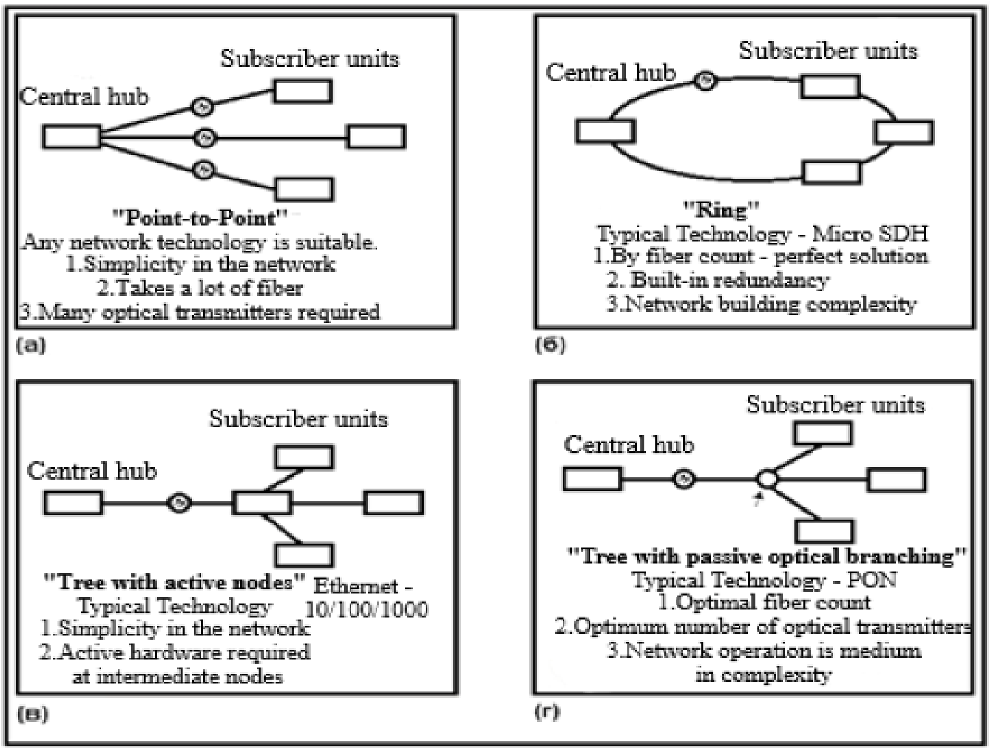

Figure 5.1 - Fundamental topologies of optical access networks

SDH-based ring topology has proven itself in urban telecommunications networks. However, in access networks, not everything is as good. If during the construction of the city highway the location of nodes is planned at the design stage, then in access networks it is impossible to know in advance where, when and how many subscriber nodes will be installed. With random territorial and temporary connection of users, the ring topology can turn into a very broken ring with many branches, new subscribers are connected by breaking the ring and inserting additional segments. In practice, such loops are often combined in one cable, which leads to the appearance of rings that look more like a polyline — “collapsed rings”, which significantly reduces the reliability of the network. And then the main advantage of ring topology is minimized.

A tree with active nodes is a cost-effective fiber solution. This solution fits well with the Ethernet standard with a hierarchy in speeds from the central node to 1000/100/10 Mbit / s subscribers (1000Base-LX, 100BaseFX, 10Base-FL).

The IEEE 802.3 Ethernet standard has long ceased to be limited to the niche of corporate networks. Networks constructed in this way can have a rather complicated and branched tree architecture. However, in each node of the tree, there must be an active device (in relation to IP networks - a switch or router). Optical Ethernet access networks that primarily use this topology are relatively inexpensive. The main disadvantage is the presence on the intermediate nodes of active devices that require individual power.

Tree with passive optical branching PON-P2MP. A special case when an optical splitter acts as a passive optical element is the PON network - a solution that is becoming widespread worldwide. The PON network uses P2MP (point-to-multipoint) topology. A single fiber-optic segment of the tree architecture, covering dozens of subscribers, can be connected to one port of the central node. At the same time, optical splitters installed in the intermediate nodes of the tree are completely passive and do not require power and specialized maintenance.

In P2MP topology, by optimizing the placement of the splitters, significant savings in optical fibers and cable infrastructure costs can be achieved. Subscriber nodes do not affect the overall network performance. Connect, disconnect or exit the failure of one or more subscriber nodes does not affect the work the others.

Advantages of the PON architecture:

- lack of intermediate active nodes; fiber saving; - saving of optical transceivers in the central node;

- ease of connecting new subscribers and ease of maintenance. P2MP tree topology optimizes placement;

- optical splitters, based on the real location of subscribers, the costs of laying OK and operating a cable network. The disadvantage is the increased complexity of PON technology and the lack of redundancy in the simplest tree topology.

An optical splitter is a passive optical multipole that distributes the flow of optical radiation in one direction and combines several streams in the opposite direction. In general, a splitter can have M input and N output ports. On PON networks, 1xN splitters with a single input port are most commonly used. 2xN splitters can be used in a redundant fiber system. According to the working passband, the splitters are divided into standard single-window (slave 10 nm), wide-band single-window (slave 40 nm) and double-window (1310 40 nm and 1550 40 nm). For PON networks, only dual-window splitters are used. In these operating windows, the characteristics of the splitter must be stable.

The principle of operation of PON. The main idea of the PON architecture is to use only one transceiver module in the OLT to transmit information to multiple ONU subscriber devices and receive information from them. The implementation of this principle is shown in Figure 5.2. The number of subscriber nodes connected to one OLT transceiver module can be as large as the power budget and maximum transceiver equipment speed allows. To transmit information from OLT to ONU, a direct (upstream) stream, a wavelength of 1550 nm is usually used. On the contrary, data streams from different subscriber nodes to the central node, together forming a reverse (downstream) stream, are transmitted at a wavelength of 1310 nm. The OLT and ONU have integrated WDM multiplexers that separate outgoing and incoming streams.

Direct flow. The direct stream at the optical signal level is broadcast. Each ONU, reading the address fields, selects from this general stream the part of information intended only for it (figure 5.2).

In fact, we are dealing with a distributed demultiplexer.

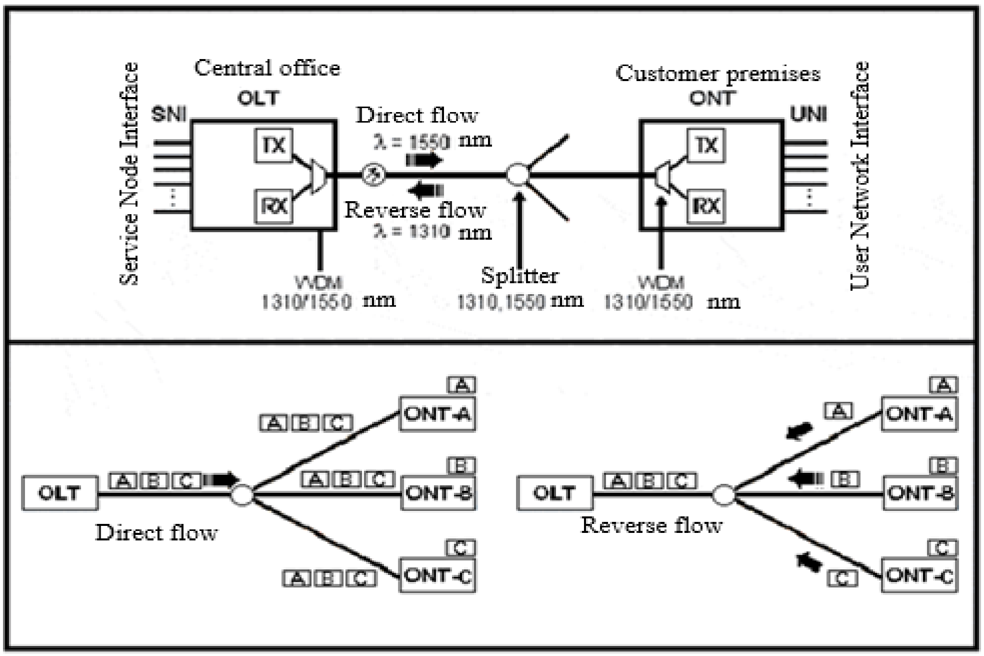

Figure 5.2 - Basic elements of the PON architecture and principle of operation

Reverse flow. All ONU subscriber nodes transmit in the reverse stream at the same wavelength using the time division multiple access (TDMA) concept. In order to exclude the possibility of crossing signals from different ONUs, each of them has its own individual data transfer schedule taking into account the delay correction associated with the removal of this ONU from the OLT. This task is solved by the TDMA MAC protocol.

APON, EPON, and GPON architectures. The first steps in PON technology (passive optical networks) were taken in 1995 when an influential group of seven companies (British Telecom, France Telecom, Deutsche Telecom, NTT, KPN, Telefonisa and Telecom Italia) created a consortium in order to implement single fiber multiple access ideas. This informal organization supported by ITU-T is called FSAN (full service access network). Many new members of both operators and equipment manufacturers entered it in the late 90s. last century. FSAN's goal was to develop general recommendations and requirements for PON equipment so that equipment manufacturers and operators can coexist together in the competitive systems market access pon. Today, FSAN has 40 operators and manufacturers and works closely with standardization organizations such as ITU-T, ETSI and ATM Forum.

Lecture №6. Next Generation SDH Transmission Systems (NG-SDH)

The purpose of the lecture: the study of a new generation transmission system (NG-SDH).

Content:

- components of NG SDH;
- protocol decision LAPS;
- GFP protocol solution;
- protocol decision LCAS.

NGSDH = GFP + LCAS + VCAT

It is generally accepted that the SDH system belongs to a new generation if it includes support for the following components:

- The General Framing Procedure (GFP), which enables the adaptation of asynchronous data traffic based on variable-length frames to byte-oriented SDH traffic with minimal delay and redundancy in headers; ITU-T G.7041;
- Virtual Concatenation (VCAT) provides the ability to combine at the logical level several VC-12, VC-3 or VC-4 containers into one data channel. ITU-T G.707, G.783;
- Link Capacity Adjustment Scheme (LCAS) allows you to implement any changes in throughput without stopping data transfer. ITU-T G.7042.

LAPS protocol solution.

SDH multiplexer with Ethernet port functions is a new generation of technology - multiservice communication networks. Such technical solutions as Ethernet over SDH became relevant in connection with the need to combine local networks and expand the range of Ethernet network services (voice, video, data, broadband interactive services). Considering the different origin and functioning of Ethernet and SDH networks, ITU-T developed means for combining, on the one hand, random packets of variable capacity, and on the other hand, cyclic transfer of VC-n, VC-m, STM-N to SDH . This was the LAPS (Link Access Procedure SDH) protocol, defined in ITU-T Rec. X.86 as an SDH line access procedure, which provides a simple technical solution for connecting separate Ethernet local networks. The LAPS procedure is a variation of the High Level Data Link Control (HDLC) protocol, a high-level communication channel control protocol approved by the International Organization for Standardization ISO. Also, this protocol is known by ITU-T standards: X.25, Q.921, Q.922. The LAPS layer location for the Ethernet-SDH interface is shown in figure 6.1. The location of the Ethernet frame data in the LAPS field is shown in figure 6.2. To coordinate the speeds, individual bytes are used in the LAPS structure with fixed filling (0x7d, Oxdd), which are indicated in the hexadecimal system. These bytes on the receiving side are discarded upon detection.

GFP Protocol Solution.

GFP technology as defined by ITU-T will provide a more efficient use of transport network resources to deliver unrealistic time data. It is on a par with ATM, but supports the transmission of frames of variable capacity (figure 6.1).

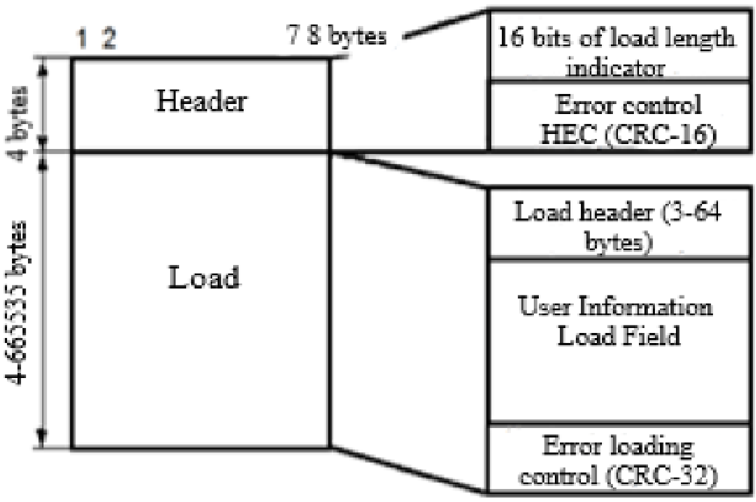

Figure 6.1 - GFP frame format

The GFP frame format may indicate a different purpose:

- custom with the transfer of traffic and control in the interests of the user;

- management with maintenance personnel, management and operation (OAM, Operation, Administration, Maintenance), i.e. functions hidden from the user and free frames.

In addition, the GFP frame is designed to implement two transmission options: transparent GFP-T (Transparented) and with the display of the user frame GFP-F (Frame mapped).

The GFP frame header field is represented by four bytes. The PDU Length Indicator (PDI Length Indicator) field indicates the binary number corresponding to the amount of user load. The minimum value for this field is 4 bytes. The volume of the PLI field is 16 bits.

GFP Framing Processes are shown in figure 6.2. The following signals are used to indicate defective states of the GFP tract:

- damage to the TSF (Trail Signal Fail) path, which is detected at the level of the SDH or OTH sections;

- service damage - loss / error of the server signal (SSF, Server Signal Failure), formed at the assembly and disassembly level of the frame;

- damage to the user signal CSF (Client Signal Fail) as a result of the formation of one of the two above signals.

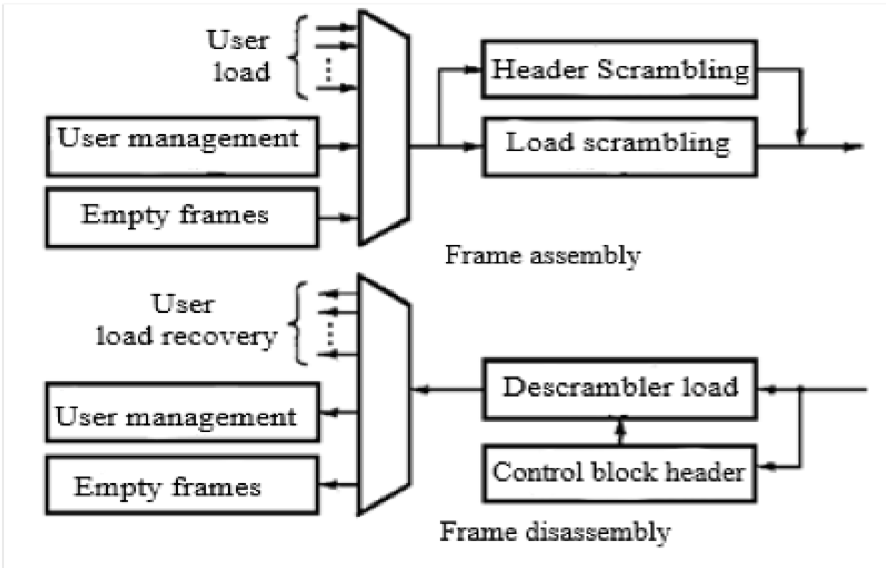

Figure 6.2 - GFP formation processes

GFP frames are divided into two types: GFP-F, GFP-T (figure 6.3). GFP-F frames are more applicable to data packets of different types and lengths. GFP-F frames assume coding for transmitting signals in 8B10B format. Examples of GFP-F load are IP / PPP packets and GbE frames.

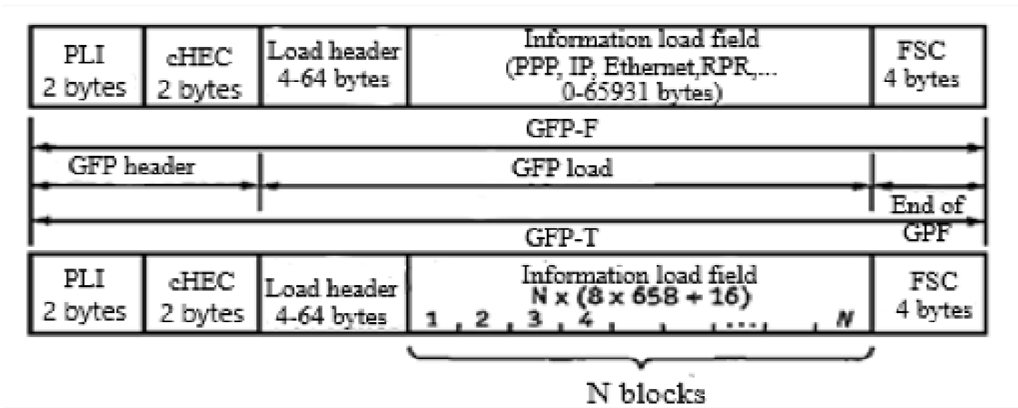

Figure 6.3 - Distinctive features of GFP-F and GFP-T

GFP-T frames are loaded with single user data with efficient super block conversion, where the load is represented by Nx67-byte super blocks, where each 65-byte block is assigned a CRC-16 code. Figure 5.5 shows the contents of the load of the GFP-F and GFP-T frames.

To encode user data in GFP-T, the 64V / 65V code is used, which converts data from the 8B10V code. The load is presented in bit dimension.

Protocol decision LCAS.

One of the latest standards developed for NG SDH is the LCAS protocol, which runs between two network elements (NEs) connecting user interfaces on an SDH network. Each H4 / K4 byte transmits a control packet consisting of virtual concatenation information and LCAS protocol.

Based on the control packet data, the LCAS protocol determines which of the VCG members is activated and how they are used and allows outgoing equipment to dynamically change the number of containers in the concatenation group in response to real-time band change requests.

These increases or decreases in the bandwidth are performed without any negative impact on the services.

For example, a company that uses a 50 Mbit / s channel between departments during a business day may need a larger band to perform backup operations after hours. LCAS allows you to automatically add the necessary band without interrupting communication.

This method allows providing an alternative protection scheme in the SDH network: connected VCAT containers pass through different network routes and in case of failure on one of the routes, the LCAS mechanisms leave virtual containers unaffected by the failure in the connection, thereby preserving the connection operability, albeit with less throughput. After eliminating the failure, the connection is restored to its original state.

NG SDH represents a new round in the development of SDH and aims to give a second life to TDM networks. This "pawn" rather saves the "king". In fact, the classic SDH is a circuit-switched transport network and, satisfying all the requirements of digital telephony, it is not able to efficiently transmit packet traffic through its channels, the share of which is constantly growing. The capabilities of NG SDH technology are based on three “pillars” - GFP, VCAT, LCAS (figure 6.4).

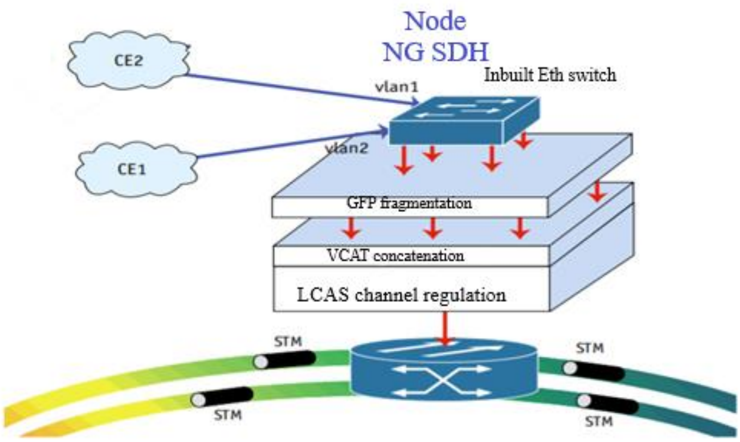

Figure 6.4 - The structure of the multiservice node NG SDH

Lecture №7. Optical Transport Networks

The purpose of the lecture: the study of optical transport networks.
Content:
–WDM classification;
–Technology of an optical transport network OTN-OTH.

WDM classification based on a channel plan.

The scheme of the extended channel plan allows us to propose the following classification scheme, taking into account modern views and tendencies to distinguish three types of WDM multiplexers:

1) Conventional WDM – MRDV.
2) Dense WDM (DWDM) – PMRDV.
3) High-density WDM (HDWDM) – VPMRDV.

WDM systems - systems with a channel spacing of at least 200 GHz, allowing multiplexing of no more than 16 channels, DWDM systems - systems with a channel spacing of at least 100 GHz, allowing multiplexing of no more than 64 channels, HDWDM systems - systems with a channel spacing of 50 GHz or less allowing multiplexing at least 64 channels.

OTN-OTH Optical Transport Network Technology.

Optical transport network OTN (Optical Transport Network) based on the multiplexing technology of the optical transport hierarchy OTN is designed to build transport routes with a throughput of up to tens of Tbit / s. This is achieved by combining flexible digital multiplexing of standard cyclic blocks, on the one hand, and the flexible construction of optical channels and their multiplexing into controlled optical modules, on the other hand.

To implement the OTN-OTH capabilities, ITU-T Recommendations G.709 and G.798 provide a hierarchical interface structure (figure 7.1), which repeats, in essence, the OTN-OTH transport network model.

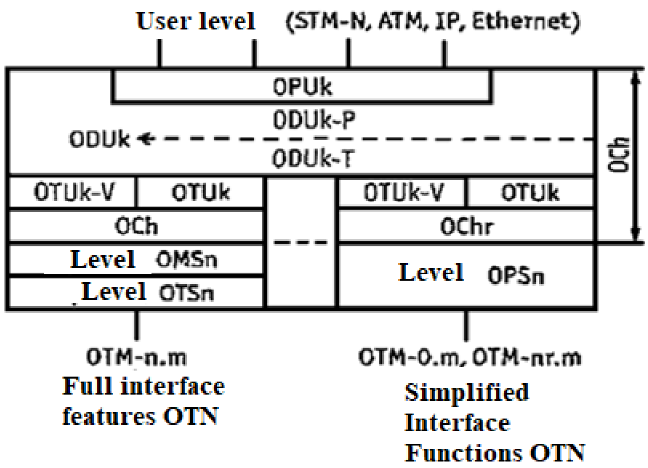

Figure 7.1 - The structure of the OTN-OTH interface

However, the technological solutions for all the constituent layers of the OTN network are emphasized in the interface structure, in particular, a complete and simplified set of interface functions is presented when forming the optical transport module of the OTM.

To implement the interface functions, electronic and optical equipment is used (figure 7.2), combined into transponder (TPD) and optical blocks (OMX) with optical relay R. The transponder blocks implement the optical channel level functions OCh (Optical Channel).

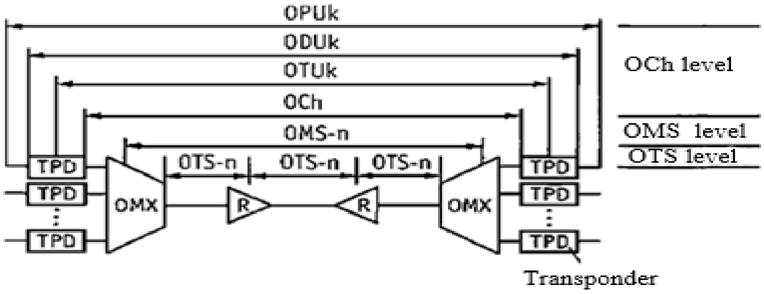

Figure 7.2 - Connection structure in the OTN-OTH network

The OCh level provides the formation of digital transport structures of the optical transport hierarchy through block generation for packing user information: OPU, ODU, OTU. Also, the OCh level provides the conversion of electrical signals into optical signals on transmission and the reverse operation on reception with the regeneration of the amplitude, shape and duration of the signal pulses (3R functions). Consider the components of the structure shown in figure 7.2.

OPUk (Optical channel Payload Unit-k) is an optical channel load unit of order k, where k ~ 1, 2, 3. This cyclic information structure is used to adapt user information to transportation in the optical channel. The OPUk block consists of an information load field and a header.

ODUk (Optical Data Unit-k) is an optical channel data unit of order k, where k = 1, 2, 3. This information structure consists of the OPUk information field and the header.

ODUk-P (ODUk Path) is an optical channel data block of order k that supports the end-to-end path of the OTN network.

ODUk-T (ODUk-TCM, ODUk Tandem Connection Monitoring) is an optical channel data unit that supports the monitoring (monitoring) of paired (tandem) connections in the OTN network. One ODUk-T unit supports monitoring of up to six tandem connections.

OTUk (Optical Transport Unit-k) is an optical transport block of order k, where k = 1,2, 3. This information structure is used to transport ODUk through one or more connections (cross-connects in nodes) of optical channels. The OTUk block is defined in two versions - OTUk-V and OTUk. It is recommended for use on local OTN sites in full and simplified forms of execution.

OTUk-V is characterized as a partially standardized structure, recommended for use as part of the OTM optical transport module in full form. OTUk-V consists of an optical channel data block, a header for controlling the optical channel connection and an FEC error correction field (figure 7.3). The OTUk block is sent to an optical modulator, where pulsed optical transmissions are formed on a specific radiation wave. The radiation waves of each OCh are combined in the equipment of the Optical Multiplex Section (OMS)

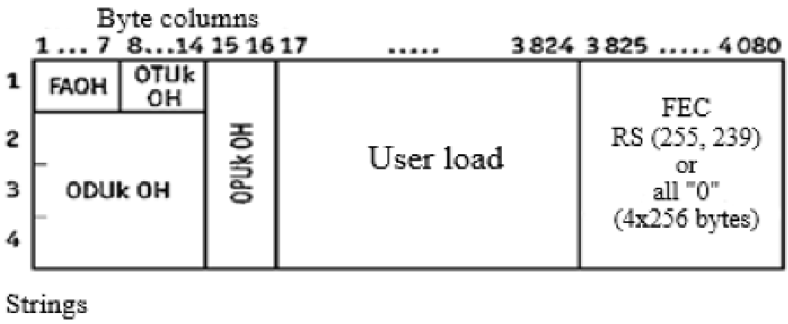

Figure 7.3 - OTUk block structure

At the level of the optical multiplexing section OMS-n, multiplexing / demultiplexing of n optical channels is performed. The number 1 <n <16 indicates the optical frequencies recommended for signal transmission through fiber-optic lines in the range 1260-1675 nm. In this range, it is possible to group optical frequencies with blocks from n into OTM-n modules for their subsequent transmission in the optical sections of the OTS (Optical Transmission Section).

Table 7.1 - Hierarchical speeds and OTUk cycles

OTUk	Speed, kbps	Speed deviation	Cycle duration, μs
OTU1	255/238 x 2 488 320	$\pm 20*10^{-6}$	48,971
OTU2	255/238 x 9 953 280		12,191
OTU3	255/238 x 39 813 120		3,035

The level of the optical physical section of the order n OPS-n (Optical Physical Section-n) is provided for transmitting a multi-wavelength optical signal through various types of optical media (single-mode fibers with characteristics G.652, G.653, G.655, G.656). The order of wave transmission is determined by the index "l", which can lie in the range 0 <n <16. There is no wave service channel in this interface.

The multiplexing and packaging scheme of the optical transport hierarchy of OTN reflects the sequence of transformations of information data and optical signals in the OTN interface. Transformation procedures are shown by arrows. The blocks of the scheme, depicted in the form of rectangles, are designed for packaging digital data. The blocks of the circuit depicted in the form of ovals are intended for multiplexing operations.

As a result of packaging operations, adapted OTU digital data units are created, which are transmitted in optical channels. As a result of multiplexing operations, ODTUG group blocks of digital data and OCG optical channel group blocks are created.

Lecture №8. Network elements of optical transport networks

The purpose of the lecture: the study of network elements of optical transport networks.

Content:

- terminal multiplexers;
- an example of an SDH network element designation.

By a network element it is customary to understand a product with a set of functions that provide interaction in a communication network with other similar devices for organizing connections, protecting them, testing, managing, etc.

The network element can be an electronic regenerator with optical interfaces, an optical amplifier, an SDH I / O multiplexer, OTH, an OADM (Optical Add-Drop Multiplexer) multi-wavelength input / output multiplexer, etc. The network element can contain both various line terminations (STM-N, WDM ports), as well as user interfaces with electrical optical termination (E1, E3, E4, STM-N, Ethernet 1000, ATM, etc.). For reliable and efficient interaction of a network element in a network, it is equipped with control and synchronization tools. The network element must also have a reliable power supply, and service communication, and alarm.

Terminal multiplexers. Terminal multiplexers combine the implementation of various transport technologies: SDH, ATM, OTH-OTN, Ethernet, T-MPLS, etc.

A terminal multiplexer with Ethernet port functions. SDH multiplexer with Ethernet port functions is a new generation of technology - multiservice communication networks.

The application of the GFP-F procedure allows you to flexibly coordinate the transfer of Ethernet 100, Ethernet 1000 data with the SDH cycles represented by VC-X-Xv virtual containers, for example, 1 Gbit / s Ethernet in GFP-F and VC-4-7v, i.e. transfer to virtually coupled seven VC-4 containers. In this case, the LCAS channel capacity adjustment function can be supported.

Ethernet interfaces in the SDH equipment are single and group (4, 8, 12 endings). Group connections often also provide Ethernet packet switch functions. This allows you to support point-to-point connections and a packet ring with a common access. In addition, Ethernet interfaces can support the functions of IP packet routers with specific quality metrics. Thus, an SDH terminal multiplexer equipped with Ethernet ports can be considered a network element of a multiservice transport network. The designation of this type of network element is shown in figure 8.1.

It should also be noted that to host Ethernet data in the SDH network, ITU-T provided an interface option with the formation of a 64V / 66V block, in which tracking units are connected to the Ethernet frame, and this frame is encoded block 64V / 66V with subsequent insertion at a speed of 10 Gbit / s in STM-64. This solution is provided for Ethernet 10 Gb / s.

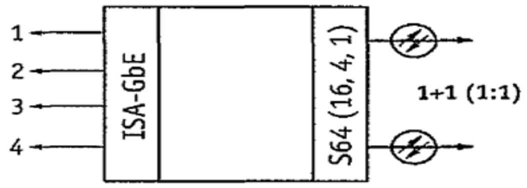

Figure 8.1 - Terminal Multiplexer with Ethernet Port Functions

A terminal multiplexer with ATM port functions. To support the functions of multiservice packet networks based on the asynchronous ATM transfer mode, SDH multiplexers can use integrated service adapter modules to create and support virtual ATM paths and channels. The structure of the modules includes: adapters for several ATM ports, for example, 16 ports, 32 ports; ATM cross-matrix to support virtual connections, for example, 8192 VP / VC connections; Means of supporting a certain quality of services with a constant, variable and non-specified data transfer rate. Ports can input / output data at speeds from 2 Mbit / s to 622 Mbit/s in accordance with ITU-T Rec. 1.432. In SDH cycles, ATM data in the form of cells of 53 bytes is placed one by one in VC-12, VC-3, VC-4. At the same time, any configuration is supported for the ATM network (point-to-point, star, ring).

An example of the designation of an SDH network element with the functions of ports and ATM switches is shown in figure 8.2.

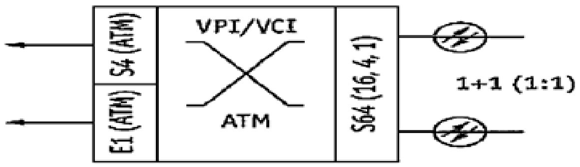

Figure 8.2 - Terminal Multiplexer with ATM Port Functions

It should be noted that SDH interfaces (STM-1, STM-4, STM-16, STM-64) are more often performed in ATM switches for multiservice networks. The option of placing ATM interfaces as part of the SDH network element is used to access and concentrate the load flow in the form of ATM cells.

Terminal multiplexer with OTH port functions. To interface SDH and OTN-OTH transport networks, multiplexers provide for the possibility of coordinated transmission of OTH cycles (ODU1 and ODU2) through VC-4-Xv linked virtual container cycles. So, to transfer data units of the optical channel ODU1 requires a linked virtual container VC-4-17v. To transfer the data unit of the optical channel ODU2, a linked virtual container VC-4-68v is required, that is, the interaction of the

OTH and SDH networks is possible only at the STM-64 level. The designation scheme for this interaction is shown in figure 8.3.

Another option for interaction in a network element involves combining the OTH-SDH functions in a different order, i.e. placement of STM-N (N = 16.64,256) in the OTN structure (OPUk, ODUk, OTUk, OTM-n.m). Moreover, it is possible to implement the protection functions of the entire multi-wave signal, consisting of OTM-nm modules (n <16, m = 1; 2; 3 (1.2; 1.3; 2.3; 1.2.3)), protection each individual optical channel with an OTUk load (k = 1, 2, 3), with an SDH network connection through the OCh wave channel switch or through the ODUk block switch.

An example of designating a network element of this type is shown in figure 8.4. In this example, the possibilities for multiplexing A are indicated, where i <n, n = 1 ... 16. A line port with up to 16 wave channels can have 100 percent line protection.

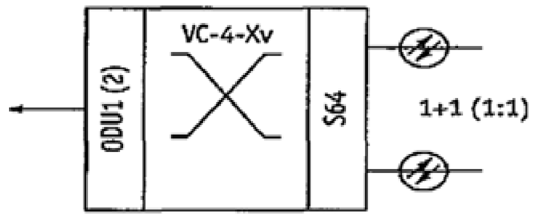

Figure 8.3 - Network element SDH, interfaced with the network OTH

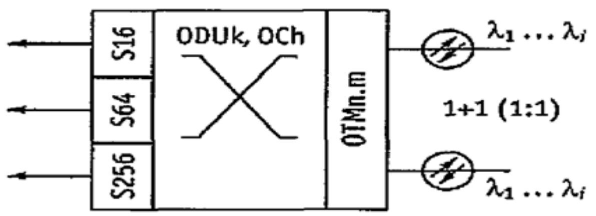

Figure 8.4 - An OTN-OTH network element interfaced with an SDH network

ADM I/O multiplexers with electrical and optical terminations. ADM (Add-Drop Multiplexer) multiplexers - the most common type of equipment for building network elements of transport networks. Output / input capabilities create the prerequisites for building various transport network architectures. At the same time, the key components of network elements are cross-connect switches, linear (aggregate) interfaces, protective functions of sections and paths, user interfaces, synchronization and control units.

The capabilities of the ADM electrical cross-connect matrixes allow access to individual high or low order component streams (VC-4, VC-12) or to all component streams. The output of one or more component streams with subsequent termination on the user interface (for example, E1 or Ethernet) may be accompanied by a ban on the input of component streams generated by STM-N. to continue using the temporary resources of this cycle.

Management in ADM is closely related to the management of the ADM group on the network. Figure 8.5 shows an example of the ADM notation.

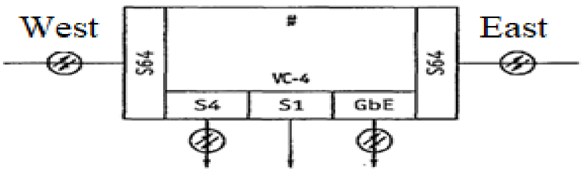

Figure 8.4 - Designation of the ADM level STM-64

The ADM multiplexer has the designation of linear interfaces as western and eastern. User (component) interfaces have optical (S4, Ethernet 1000) and electrical (S1) terminations. The multiplexer can be connected to linear and ring networks. At the same time, a complete set of units can provide protection for multiplexing sections from the west and east (figure 8.6).

The resource capacity of the ADM multiplexer is determined by the capabilities of aggregate interfaces. For example, if the ADM has two linear STM-16 interfaces, then the equivalent number of the maximum available user interfaces of the E1 level will be 2016. In comparison with the terminal multiplexer, it is twice as much.

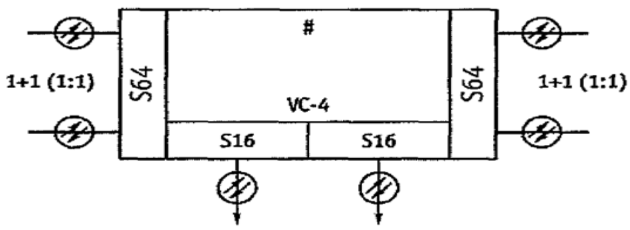

Figure 8.6 - ADM Multiplexer with Line Interface Protection

ADM multiplexers, like TM multiplexers, are included in ASON networks and in networks with multi-wavelength WDM transmission. An example of the inclusion of ADM and OADM is shown in figure 8.7.

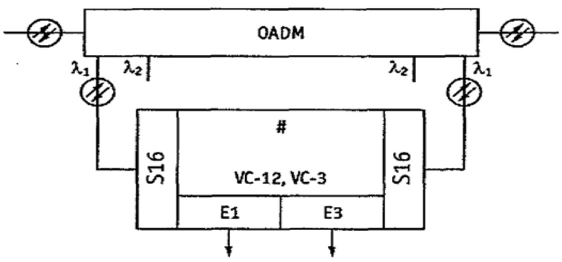

Figure 8.7 - ADM Multiplexer and OADM Optical Multiplexer

Lecture №9. Synchronization, management and protection in transport communication networks

The purpose of the lecture: the study of control synchronization systems in transport communication networks.

Content:

- synchronization in transport networks;
- management in transport networks.

Processing of digital signals in various systems (transmission, switching, multiplexing, etc.) must be performed in strict sequence in time and synchronously. The digital signal receiver must always work in synchronization with the transmitter. Only this condition, fulfilled completely, contributes to the error-free transmission of digital data. Consequently, the pulse transmission cycles created by the transmitter should synchronize the operation of the receiver. The problem of clock synchronization is found at the junction of digital systems (transmission systems and switching systems), which have independent clock mechanisms. The frequencies fi and / 2 may not coincide. In addition, write and read cycles may be out of phase. The clock phases of the frequencies fi and / 2 can drift in time. Changing phases with a frequency above 10 Hz is called jitter. Change of phases with a frequency of less than 10 Hz is called wandering or wander.

As a result of the difference in the frequencies and phases of the clock cycles of writing data to the buffer memory and reading them, unnecessary temporary bursts may appear, which will overflow the buffer and be lost, thus, their disadvantage may arise, which will lead to a false reading of the buffer of undefined bursts. Ultimately, this can lead to failure at higher levels of digital processing. For example, the sequence of data of synchronization words in cycles, in over-cycles is disrupted, and the synchronization sequences of network data packets are destroyed: ATM, Ethernet, and others. In turn, this can lead to the loss of a part of information messages and to a deterioration in the quality of communication services. The phenomenon of skipping or repeating bits in a digital signal read from the buffer at the junction of the systems is called Slip.

Slips are divided into two types:

-controlled slippage that does not lead to a failure of cyclic synchronism, while the lossy signal restores synchronism;

- uncontrolled slippage, which lead to loss of cyclic synchronism and irreparable loss in a digital signal.

Quality of service G.801. Sliding Standards G.822 Timing Chain Model G.803. Standards for equipment SDH G.957, G.958. Standards for generators (G.811, G.812, G.813). Standards for jitter and wander (G.823, G.825)

Clock network synchronization network operating mode ITU-T Rec. G.803 defines four synchronization network operating modes: synchronous; pseudo-synchronous; plesiochronous; asynchronous.

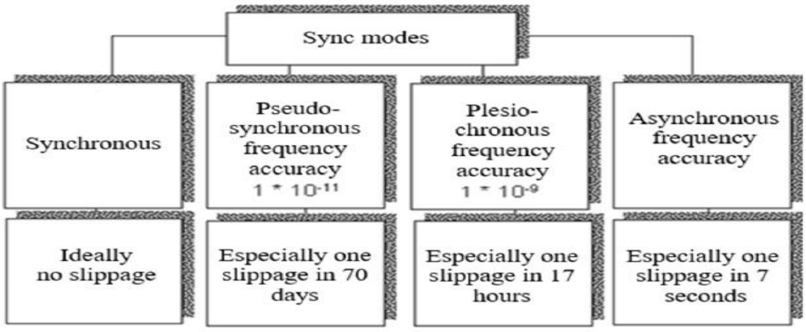

Figure 9.1 - Synchronization modes

Management in transport networks. Transport network management refers to the tasks defined by the general concept of telecommunication network management, which is called the Telecommunications Management Network (TMN). In this concept of the International Telecommunication Union, standards have been developed for building a management system for communication networks. Management standards are published as ITU-T Recommendations of the M.Zxxx series.

The management network (SU), according to the TMN concept, provides management functions for telecommunication networks and the services of these networks (figure 9.1). In addition, various SU concepts have been developed for telecommunication systems of enterprises, departments, associations that profess the principles of platform management using the Simple Network Management Protocol (SNMP), the Common Object Request Broker Architecture (CORBA) protocol, etc.

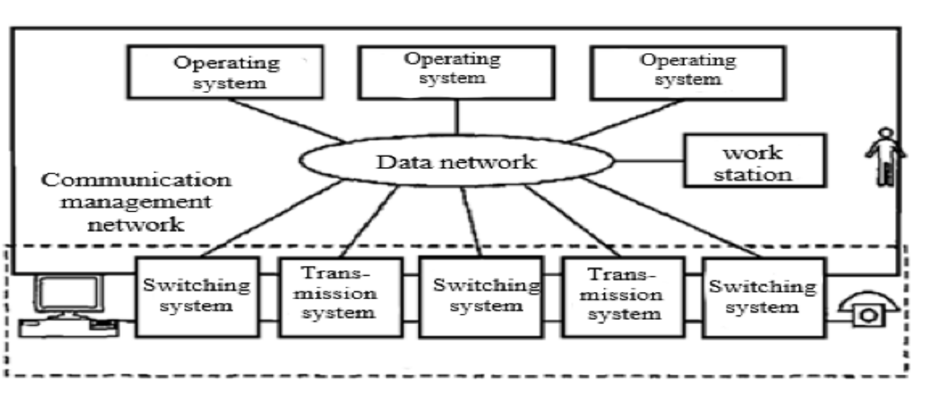

Figure 9.2 - The relationship of the management network and the managed network

The management network is independent of the managed network. Network interaction is implemented through the interfaces of switching stations, transmission systems and user terminals. Separate data channels are provided for this purpose. The SDH network uses channels based on the bytes of the headers of the regeneration and multiplexing sections (bytes Dl .. .D3 form a DCCr channel with a speed of 192 Kbit / s in the RSOH header, bytes D4 ... D12 form a DCCm channel with a speed of 576 Kbit / s in the MSOH header) . OTN-OTH optical network uses channels based on the OTUk and ODUk header bytes (two GCC bytes in the OTU1, OTU2, OTU3 headers and two GCC1, GCC2 bytes in the ODUl, ODU2, ODU3 headers support transmission rates respectively 326.723, 1312,405, 5271.864 Kbps). In transport networks based on ATM and Ethernet technologies, control data transmission channels are also organized, however, these channels are virtual, i.e. formed by a random stream of cells or frames and have a variable transmission rate. In this case, the control information is recorded in the load fields of the cells and frames, and the network address of the network element or the address of the control node is indicated in the headers of the cells and frames.

The TMN concept provides for a hierarchical construction of the control system, which has a pyramidal shape (figure 9.3).

The lowest level "Network Elements" is a managed network with all its network elements, their resources and states. Each overlying management level has a higher degree of generalization of management information than the one below.

The "Network element management" level includes monitoring, fixing the operating parameters, maintenance, and configuration for individual network devices (for example, optical multiplexers, cellular base stations, channel or packet switches). The functions of this level, sometimes called zero, can be performed using a graphic terminal that can be connected directly to a network element or remotely, i.e. through a data network.

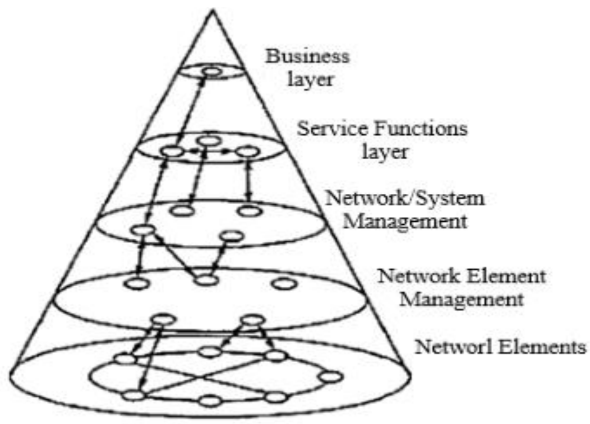

Figure 9.3 - TMN control pyramid

The "Network management" level provides management functions for a group of network elements that make up a single network with all resources, for example, an optical transport network with optical multiplexing sections, optical or electric paths, channels, backup and synchronization tools.

The Service Management layer supports the provision of telecommunication services to users, i.e. in contrast to the levels below it is aimed at consumers of communication services. The key factor at this level is ensuring the quality of services, attracting consumers with new services.

The level of “Administrative management” is intended for support the functioning of the company-operator of the communication network. At this level, the problems of investment, development projects, staffing, interaction with other operators, government, etc.

Lecture №10. MPLS Transport Technology

The purpose of the lecture: studying the architecture of multi-protocol label switching (MPLS - Multi-Protocol Label Switching).

Content:

- MPLS architecture;
- switching process.

The MPLS architecture is governed by the IETF's Multiprotocol Label Switching Architecture (RFC3031).

In traditional IP networks, in general, packet routing is based on the destination IP address. Each router on the network has information about which interface and which neighbor should forward the incoming IP packet to.

In MPLS, each IP packet is assigned a label. Routers decide to forward the packet to the next device based on the label value. The label is added as part of the MPLS header, which is added between the frame header (OSI layer two) and the packet header (OSI model layer three) (figure 10.1).

Frame header	MPLS header	IP Packet header	IP packet

Figure 10.1 - The location of the MPLS header in the frame

The MPLS header format is shown in figure 10.2.

Figure 10.2 - Format of MPLS tags

Description of the MPLS header fields:

a) label - the label itself, by which switching is carried out; CoS - a field that describes the class of service of the packet (analogue of IP precedence); TTL - time-to-live - analog of IP TTL;

b) S - several labels can be assigned to one packet (“stack” of labels). S - flag field indicating that the label is the last in the “stack”. An example is shown in figure 10.3.

Frame header	MPLS header №3	MPLS header №2	MPLS header №1	IP packet header	IP packet

Figure 10.3 - Example of label stack assignment

Within the MPLS architecture, the following device types are distinguished:

1) LSR - Label-Switch Router - a router that supports label switching and traditional IP routing.

2) Edge LSR - a router connected to devices that do not perform label switching (devices may use a different routing policy or do not support MPLS at all).

3) MPLS domain - MPLS domain - a group of connected devices that carry out label switching, are under a single administrative subordination and operate in accordance with a single routing policy. An MPLS domain is formed by LSRs, and E-LSR devices are located at the domain boundary.

4) LSR performs two processes: routing and label switching. The routing process operates on the basis of an internal routing protocol (for example, OSPF). The routing process receives routing information from neighbours and generates a routing table. The routing table is used to route ordinary IP packets.

The switching process operates on the basis of the Label Distribution Protocol. The label exchange protocol negotiates specific label values to create holistic label switching routes (LSPs). The label switching process also uses the IP routing table to compile the switching tables. The interconnection of label switching processes and IP routing is shown in figure 10.4.

It should be noted that the uniqueness of labels is provided only at the interface level, that is, for two different input interfaces the same label values can be found (in the switching table, the first and second entries). Thus, a packet arriving at tag 100 from the Serial1 interface and a packet arriving at tag 100 from the Ethernet2 interface will follow different LSPs. A unique combination is the inbound interface and the label. And for this unique combination, the output interface and the operation that must be performed on the label are uniquely determined. This approach allows the formation of holistic LSPs between E-LSRs.

Note: Different manufacturers may implement the LSR / E-LSR architecture in different ways. For example, it is possible to use a combined IP routing and MPLS switching table. Or use three tables: one for traditional IP routing only, one for labeling, and one for MPLS switching. The LSR / E-LSR architecture described in this document is just an abstract model.

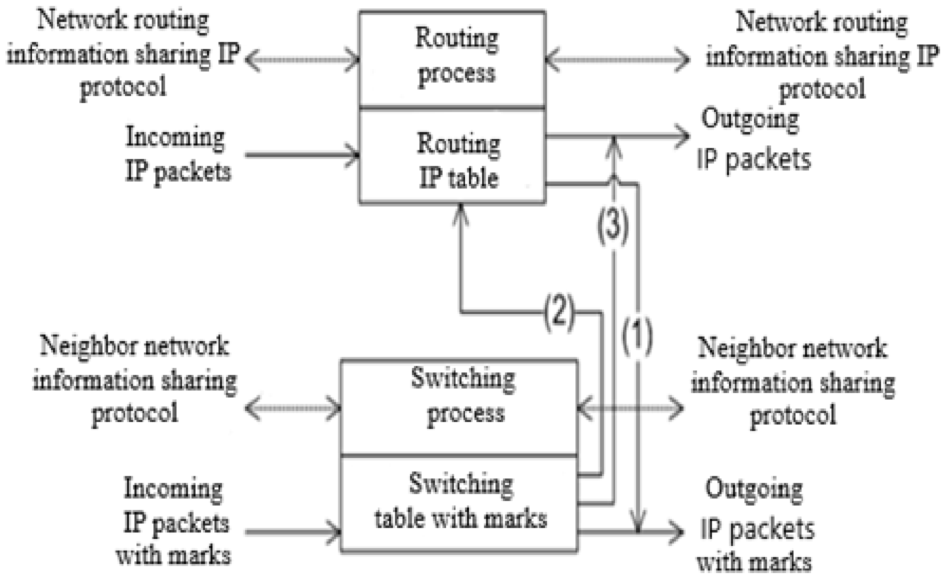

Figure 10.4 - Interconnection of MPLS switching processes and IP routing on LSR / E-LSR

T-MPLS provides managed point-to-point connections to various client networks (for example, based on Ethernet). To meet the standards of traditional transport networks, it is necessary to maintain appropriate reliability, recovery tools and quality of service. In T-MPLS, this is solved thanks to: y the introduction of OAM (Operations, Administration and Maintenance) tools new to MPLS. Through special OAM applications, network monitoring is performed, including monitoring the connectivity of nodes, identifying and localizing problems, diagnosing network problems, determining whether the connection parameters match the SLA level; y ensuring network survivability through protective switching functions: linear (1 + 1, 1: 1, 1: N) and ring. One of the main factors keeping operators from upgrading backbone networks to IP / MPLS is their complexity in setting up and managing and, as a result, expensive equipment.

GMPLS: the ubiquitous label Generalized MPLS (Generalized MPLS) is not another transport network technology, but a concept that completely separates the network management plane from the data transmission plane, which allows achieving a number of effective properties: a single control plane that has proven itself in MPLS networks, and label switching at any technological level. GMPLS extends the classic MPLS with additional mechanisms and protocols to extend the label switching paradigm to all existing transport technologies.

The evolution from MPLS to GMPLS required the expansion of existing MPLS routing and signaling protocols. To provide generalized label switching, uniform signaling and integrated routing, the OSPF-TE, IS-IS-TE, RSPV-TE, CRLDP protocols were modified (figure 10.4).

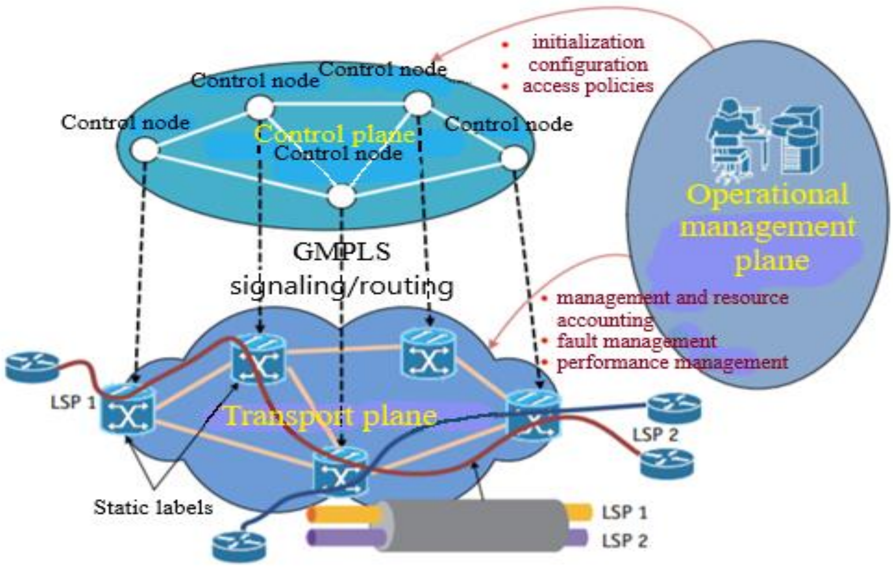

Figure 10.4 - Structure of a T-MPLS network with a GMPLS control layer

10.1 - The main functions performed by E-LSR / LSR-s

Function	English name	Description
Traditional IP packet routing	IP routing	Incoming IP packets are routed based on the routing table.
Label assignment	label imposing	If the device functions as an E-LSR, then for the incoming IP packet based on the IP routing table, the label to be assigned and the output interface through which the packet should be forwarded are determined (1).
Tag Switching	label swapping	Incoming IP packets with labels are processed by the label switching process, which on the basis of the label switching table determines which of the following actions will be performed: - forwarding the packet with changing the label through a specific interface (label swapping). With this operation, it is possible to assign additional tags to the "stack"; - unmarking and one of the following actions; - if the label was the last on the stack, then the packet is passed to the routing process of IP packets (2) (traditional switching) or forwarded through a specific interface (switching with PHP) (3); - if the label was not the last on the stack, then the packet is sent through a specific interface.
Unmark PHP	label poping with PHP	
NOTE - The output interface is determined based on the label switching table.		

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Katipa Slambayevna Chezhimbayeva

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