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RESEARCH AND DEVELOPMENT OF EFFICIENT INTRA-DOMAIN MODELS AND STRUCTURES OF OPTICAL HIERARCHICAL NETWORKS, BASED ON Λ-MPLS METHOD

The paper analyzes main problems in modern hierarchical optical networks with λ-MPLS routing. Investigations of the main characteristics of the speed and bandwidth of different network models, based on λ-MPLS method. On the basy of studies their main advantages and disadvantages are defined , ways to improve the basic characteristics are shown. The approach, aimed at increasing of bandwidth capacity, based on using universal model of distributed λ-MPLS - chains of specialized routers, switches is suggested. Comparative analysis of λ-MPLS technologies at different levels of network hierarchy over the traditional technologies with IP-routing is carried out, basic optimal ways of increasing information bandwidth capacity are determined.

Key words: *communication channels, information networks, λ-MPLS model, network topology, network nodes, traffic.*

Introduction and problem set-up

Modern methods of switching and routing such as OSPF and IGRP/EIGRP based on IP in modern optical information computation networks with and SDH/SONET/ATM hierarchy, do not always give necessary technical characteristics of the performance of ICN, latency time (transmission delay) as well as amount of lost packets as a result of invalid tables of routes construction. Traditional technologies of routing and switching in optical networks give place to new methods and models, based on optical switching and routing by labels – these are optical MPLS protocols and architectures, constructed over IP-optical networks (Fig. 1) with obligatory WDM-multiplexing in reference networks on the 1st level of OSI models [2].

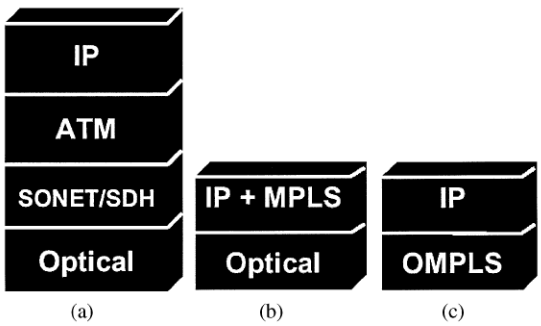


Fig. 1. Scheme of TCP/IP protocols stack in IP-networks with IP-networks with WDM-reference networks: a) traditional approach; b) network construction on IP/MPLS base; c) construction of the network with IP/OMPLS [1]

Technology of fast switching of packets λ-MPLS in multiprotocol information – computation networks, is mainly based on the usage of optical labels. Optical MPLS or λ-MPLS combines the advantage of switching rate and wide functional possibilities of traffic management, inherent to channel level technologies (L2) – switching of OSI model, with scaling and flexibility of protocols, characteristic for the network level (L3) – routing. Architecture of MPLS provides the construction of data transmission networks, having practically unlimited possibilities of networks scaling, increased aggregation (processing) rate of traffic and the possibility of adaptation for organization of various types of additional services.

In conventional IP networks, in general case, packets routing in carried out on the base of IP-address by EGRP or OSPF protocols. Each router in conventional IP-networks possesses information regarding by what interface IP-packet must be sent and takes independent decision about transfer.

In MPLS protocols another approach is considered, when data packet is associated with this or that class of network level, each of which is identified by certain label. In optical MPLS these labels are presented by wavelengths, which are identified by WDM/DWDM-infrastructure of the networks and corresponding aggregation of the packets by labels λ-LSR – is performed by routers.

By the value of packet label it membership to the frame at each of the sections of switching route is determined. Label value is unique only for the section of route between neibouring nodes of optical network λ-MPLS. Optical label, coded by certain wavelength λ_i is transferred within any packet, the way of its connection with the packet depends on the technology of channel level IP, (L3) used. Routers make a decision, regarding the transfer of the packet to the next device proceeding from the value of the label. λ-MPLS creates the model of optical connection, using WDM-technology, imposed on conventional structure of ICN. Technology of ICN construction on the base of λ-MPLS is built over IP technology, on the base of Optical Ethernet (OE), connecting the possibilities of fundamental process of routing with high performance and rate of switching process.

The most important possibilities of λ-MPLS are: high speed of packets switching as a result of using optical tracks of input/output; distribution and multipurpose control of IP-traffic in multifunctional networks; creation of safe VPN-connections between different nodes; independence of IP stacks and MAC addresses for spaces of operator and client networks. In general cases IP/ λ-MPLS technology is the base for realization of a number of services, such as:

– creation of virtual private networks λ-MPLS L1, L2, L3 and VPN;

– organization of the channels of point-to-point (P2P) type, «Virtual allocated wire service» (VPWS, Virtual Private Wire Service,) or «MPLS TRANSPORT» (a variety of Any transport over MPLS, AoMPLS);

– emulation of distributed HCN and LCN ;

– efficient management of packets flows/ IP-traffic by VPN channels of MPLS.

By indices of latency time (delay) and switching, due to the lack of aggregation of data packet content and its heading, λ-MPLS technology enables to increase considerably the performance of ICN as a result of: 1) unloading of processor resources of switches, routers L2/L3 (E-LSR); 2) reduction of switching/routing time $t_{L2/L3}$ due to the application of faster optical flows and hardware-software facilities of their processing in optical WDM-networks and channels with the type of WDM technologies: SWDM/(HDWDM)/DWDM/CWDM; 3) multiprotocol nature of optical λ-MPLS-architecture – it enables to impose λ-MPLS over a large number of available optical ICN, based on IP, that makes such configuration scalable, flexible and transparent in greater part of intradomain structures.

In literature, devoted to relatively new innovation method λ-MPLS problems of intradomain organization of ICN and LCN on the base of λ-MPLS [3] are well studied, but technologies of external domain and external networks organization of λ-MPLS optical networks are not profoundly considered, this is of great interest and actuality for the sphere of modern networks, including the Internet.

Modern challenges and requirements to information systems create the need to develop new approaches to organization of λ-MPLS architecture, based on flexible models that can be used at all hierarchical levels of optical networks in order to increase their performance and scaling simplicity.

Aim of the research

The aim of the research is to increase information carrying capacity in hierarchical optical networks, using λ-MPLS routing.

Technologies of optical hierarchical networks and organization of their channels rapidly develop nowadays. Performance parameters of modern computing networks, based on intra -domain λ-

MPLS (MPLS: networks IP/MPLS) are up to 10-100TFlops at the rate of data transfer up to 200 Gbit/sec per channel [2, 3]. As a result the advantage of using fibre-optical networks and mechanisms, as a medium for data transfer, optical devices with high carrying capacity up to tens and 300 Tbits/channel (bandwidth – 1.5-2x10^{14} Hz and low attenuation <0.01 – 0.02 dB/km) are used.

Study of conventional models and processes of intra -domain optical λ-MPLS switching

Conventional model of intra -domain λ-MPLS architecture of optical hierarchical ICN (Fig. 2, Fig. 3) is built on the base of interconnections with λ-LSR routers. In such case the domain is built on the base of Label Switch Router (λ-LSR) which organize Label Switched Paths (LSP).

In this event LSR, that makes labels in MPLS packets and eliminates labels or intercept packets with labels, organizes the route path within λ-MPLS domain.

Protocol, used in LSR-routers is called Label Distribution Protocol (LDP) and is used for data exchange (it is described in specification IEEE RFC +3036).

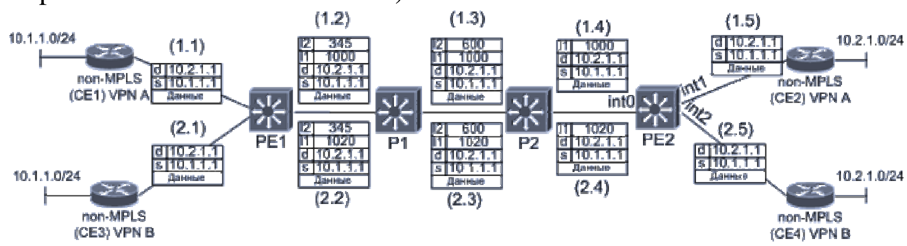


Fig. 2. Model of Label Switched Path (LSP) organization within the domain on the base of λ-MPLS and the process of VPN packet transfer via MPLS-route

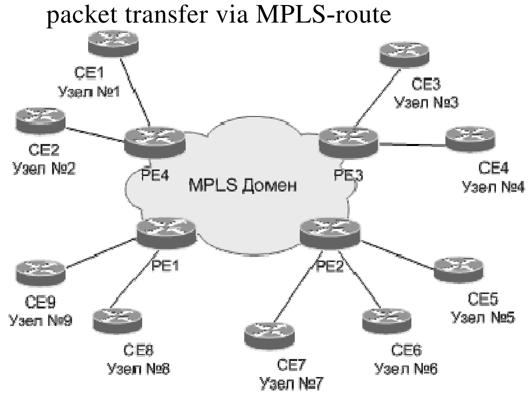


Fig. 3. Model of λ-MPLS domain (intra- domain λ-MPLS organization with internal VPN

Types of existing λ-LSR:

– optical λ-EDGE λ-LSR (E-LSR) – λ-LSR router, that is located on the edge of λ-MPLS network and processes IP packets in the stack of protocols TCP/IP with labels and without labels. Also it is called Optical Label Edge Router (LER);

– INGRESS λ-E-LSR – router of a specific packet, that performs aggregation of packets without label, prior to putting the label in the packet;

– λ-EGRESS (λ-E-LSR) – router of a specific packet, that performs aggregation of packets with label and then eliminates all the labels of MPLS and transfers IP-packet further in the network TCP-IP to other routers.

It is obvious that such model of intra-domain organization of optical ICN on the base of λ-MPLS due to greater spectral efficiency F_S will have more advantages as compared with conventional structure of IP-networks, taking into account the criterion of ICN information carrying capacity edge and switching networks – Hartley-Shannon criterion [4]:

$$C = W\,log_2(V + \frac{S}{N}) = W \times F_S = \frac{0.44}{\tau_z} log_2(V + \frac{S}{N})\,, \qquad (1)$$

where W – spectral width of the channel (band width), S/N – signal/noise ratio, F_S – spectral efficiency of the system; τ_z – value of total dispersion of data transfer channel system; V – number of signal levels for digital systems $V=2$.

Total amount of traffic, transferred into intra-domain ICN, will be determined by the amount of active existing channels in the domain – n_{ch} and with the account of (1) will be expressed as:

$$C_{tr} = n_{ch} \times W \times F_S = \frac{0.44 \cdot n_{ch}}{\tau_z} log_2(V + \frac{S}{N}), \quad (2)$$

Performance gain in conventional intra-domain λ-MPLS networks may be evaluated by minimal transfer time of packet heading $T_{загMPLS}$, that is defined by the following relation:

$$T_{загMPLS} = m(T_p + D(K_{MPLS} - 1)\Delta\lambda_{MPLS} L). \quad (3)$$

In this case carrying capacity of one branch of λ-MPLS domain will be defined as:

$$C_{MPLS} = W \times F_S = \frac{1}{T_Z} \times F_S = \frac{1}{T_{IP} + T_{AGREG} + k_i T_{загMPLS}} \times F_S, \quad (4)$$

where k_i - coefficient of impact proportionality of heating time on the width of packet pulses (may have sign ±); T_{IP} - time of IP packet latency; T_{AGREG} - aggregation time of the packet in TCP/IP networks and in routers λ-EGRESS (λ-E-LSR) .

It is obvious, that comparing conventional networks TCP/IP on the base of OSPF or EIGRP by λ-MPLS routers ICN will have far less total time of $T_{Z\ TCP/IP} >> T_{Z\ \lambda\text{-}MPLS}$ latency due to the lack of IP-packets content aggregation in the middle of the domain and more rapid switching.

Carrying capacity of the main circuit with packets switching and statistic multiplication for λ-MPLS will be determined as:

$$BW_{\lambda-MPLS}(i) = C_{MPLS} \times \frac{\bar{L}_{layer}(i)}{\bar{L}_{packet}(i+1)} \cdot K_{usable} \cdot R(i), \quad (5)$$

where $\bar{L}_{layer}(i)$ and $\bar{L}_{packet}(i+1)$ – hierarchy layer of ICN network on the base of λ-MPLS; K_{usable} – coefficient of layer usage; $R(i)$ – function of network load distribution by layers.

The model of construction of signal chain of intra-domain hierarchical ICN on the base of λ-MPLS (shown in Fig. 4) with coding of each label by packets at each of wavelengths λ_c from total range λ_1 .. λ_c .. λ_k (λ_i and λ_1.. λ_k) is presented by labels coding graph (Table 1). Thus : $M_{\lambda i}$ = SUM λ_i (λ_1=1 for λ_k).

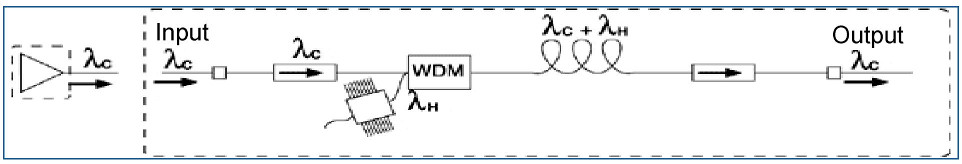


Fig. 4. Model of single chain of intra-domain hierarchical ICN construction on the base of λ-MPLS

Wavelength Δλ spacing is determined by minimal value of labels recognition by optical switching circuits:

$$\Delta\lambda = \frac{\left[\int_0^{\lambda_k} S(\lambda_i)(\lambda_i - \lambda_{ic})^2 d\lambda_i\right]^{1/2}}{S_0(\lambda_i)}, \quad (6)$$

where, $S_0(\lambda_i)$ – spectral distribution of central wavelength power relatively label λ_i.

Table 1

Graph of λ_c labels coding from total amount of M for $M_{\lambda i}$ =5

λ_1 (label 1)	λ_k (label 2)	Total amount of labels $M_{\lambda i}$ (λ_1) &λ_k labels (bit 2)
1310	1510	1
1320	1520	2
1330	1530	2
1340	1540	2
1350	1550	1

Real formed labels λ_i have not a discrete spectrum, but a certain formed spectral band $\Delta\lambda_i$, due to nonideality of laser supply sources and distribution of radiation power in certain spectral area $S(\lambda_i)$. In this case, final width of the label in optical λ-MPLS will be far more wider and this factor must be taken into account.

In data transfer systems without feedback the method of noiseless coding is realized in the form of retransmission [4]. But for high productive networks with fast acting channel the given method is not acceptable, as it will contribute to speed decrease and decrease of hierarchical optical ICN performance.

Labels during WDM-multiplexing in fiber-optical channels of λ-MPLS networks are determined by the sum of integrals (taking into account the formula for total amount wavelengths spectra in such channels during WDM-multiplexing):

$$N_{S(\lambda)} = \sum_{i=1}^{N} \int_{\lambda_{ilow}}^{\lambda_{iupx}} S(\lambda_i)d\lambda_i + \sum_{j=1}^{M} \int_{\lambda_{jlow}}^{\lambda_{jup}} S(\lambda_j)d\lambda_j, \quad (7)$$

where, $\lambda_{ilow} - \lambda_{iup}$ – spectra boundaries $S(\lambda_i)$ for single label of information channel; $\lambda_{jlow} - \lambda_{jup}$ – spectrum boundaries $S(\lambda_j)$ for single bit of information packet; N, M – number of labels and, correspondingly, bits, in information packet of multiplexing channels.

In general form graph of labels distribution in ICN and hierarchical systems λ-MPLS will have spectral area, shown in Fig. 5.

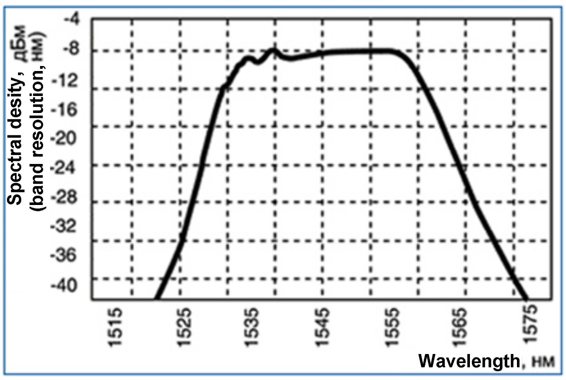


Fig. 5. Operating spectral area of labels formation by λ-ESR – routers in optical λ-MPLS of hierarchical networks

This dependence is well adapted in standard components of fibre-optical communication lines, including standard WDM systems, operating with EDFA-amplifiers.

Traditionally labels formation occurs in areas at wavelengths near main working windows of fibre-optical communication lines of transparency 1330 nm; 1480 nm; 1550 nm.

For construction of the process of intra-domain λ-MPLS modeling it is necessary to present the resulting function of amplitude signal at various wavelengths λ_i and λ_{i+1}:

$$A_m(t) = [A_{m\lambda i}(t) Sin(w_{\lambda i}t + \tau(\lambda_i))] \cup [A_{m\lambda i+1}(t) Sin(w_{\lambda i}t + \tau(\lambda_{i+1})]. \qquad (9)$$

The factor of chromatic dispersion [5], that is composed of material τ_{mat} and wave τ_w components is taken into account and is manifested in all types of optical fibers. Material component τ_{mat} is stipulated by the dependence of refractive index of the fiber $M(\lambda)$ on the wavelengths λ [6, 7], as:

$$\tau_{mat}(\Delta\lambda, L) = \Delta\lambda \times L \times \frac{\lambda}{c}\frac{d^2 n_1}{d\lambda^2} = \Delta\lambda \times L \times M(\lambda).$$

In Fig. 6 for process modeling main analytical assessments (modeling in the environment OptiSim R-Soft [TM]Trial) of the impact of dispersion in λ-MPLS intra- domain hierarchical networks (channel by the model of λ-MPLS domain is shown in Fig. 3, Fig. 5).

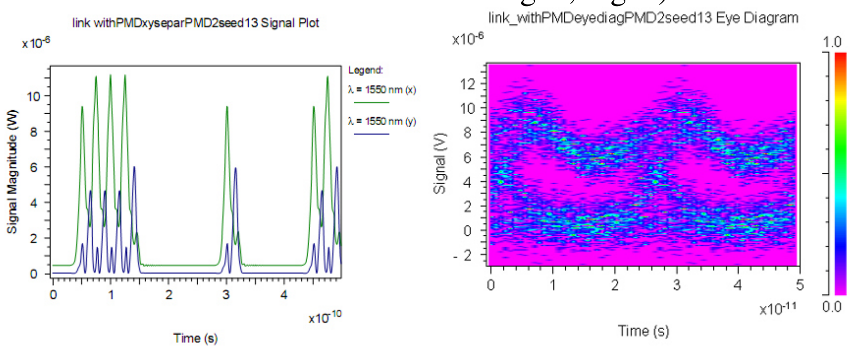
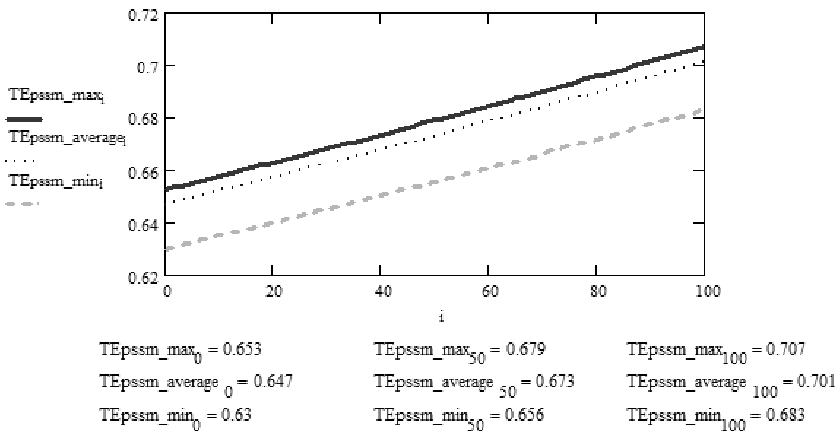


Fig. 6. Main analytical assessments of dispersion impact in λ-MPLS – intra-domain ICN

The given research contains basic analytical assessments of intra-domain ICN model (Fig. 7) on the base of λ-MPLS – by mathematical model (4), (5), taking into account (11) in the MathCAD 14 analytical expressions for reaching better performance were obtained (Fig. 7).



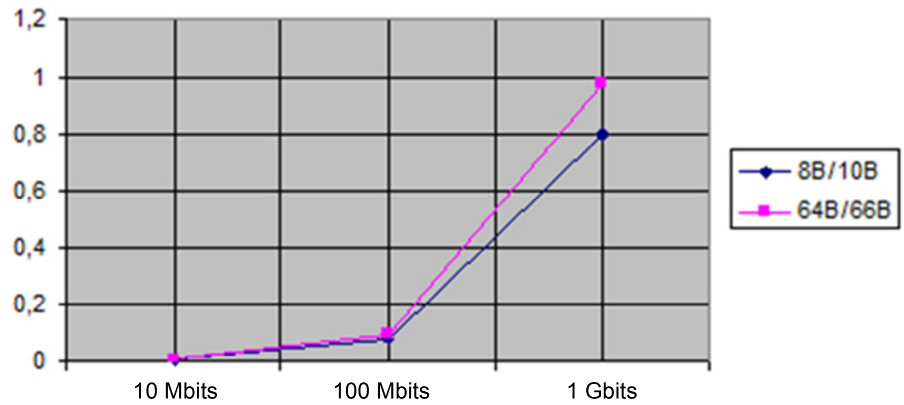


Fig. 7. Results of modeling of transfer time and carrying capacity dependence in IP networks and in intra-domain ICN λ-MPLS at various parameters of network loading on the base of Optical Gigabit Ethernet standard

The computer model is shown in Fig. 8.

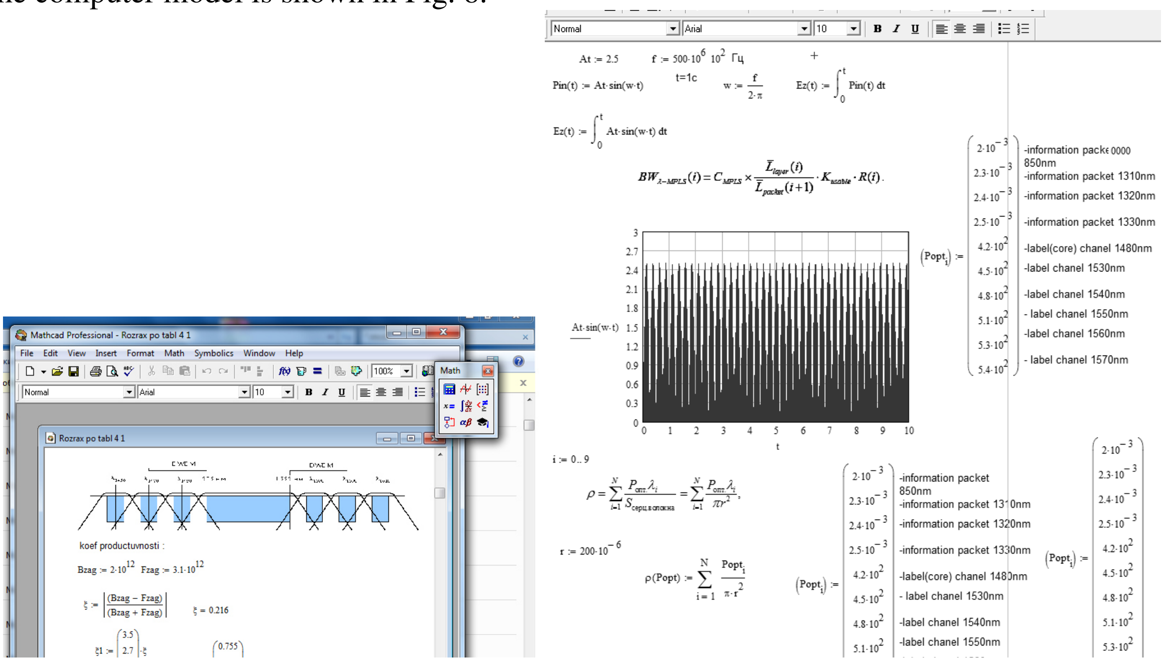


Fig. 8. Computer model of data transfer process in ICN domain on the base of λ-MPLS

In Fig. 8 function of network packet load distribution by layers $R(i)$ is set, depending on the degree of non-uniformity of the traffic, using switching λ-MPLS tract. Considerable improvement of optimization degree of intra-domain network model operation and carrying capacity during the transfer of non-uniform mixed traffic and, accordingly, load value could be obtained, using multilevel hierarchical technology. Suppose, that in the network λ-MPLS, located above ATM or FrameRelay, IP-packet are transferred. Average time loading of the channel –tract is shown in Fig. 8.

Average size of Internet-packet (IP-packet) at present is 1500 bits. Each packet contains service information of IP protocols (20 bytes), TCP (20 bytes), HDLC (6 bytes), the latter is omitted in the process of switching by λ-MPLS (1500-bit IPv4 packet contains 320 bits of service information $L_{service}$ on the levels 3 – 5 and 2032 bits of data B_{data}). Besides, prior to transfer to AAL5 additionally 8 bytes of AAL5 frame and 8 bytes of LLC/SNAP are connected to each packet, i. e. $L_{aal5} = 8 \cdot 8 + 8 \cdot 8 = 128 \ (bits)$

The results of modeling show that most of all at high speeds and degree of network load, as well as large traffic packet latency in intra-domain λ-MPLS is influenced by the size of the packet and amount of possible switching channels (IP-packets of small size carry large volume of service information) and maximum load that can be supported by corresponding λ-ESR router or switch (L3). If the volume of the load is increased to the value of 90 – 95%, then for the frame of 1514 bytes (of IP-packet) in the given model load value will be 3.57.

The advantage of noiseless coding in λ-ESR- routers is:

– Possibility of processing (aggregation) of multi-core headings;
– More rapid time of switching on;
– Increase of switching node transfer coefficient;
– Lack of the necessity to have the port by de-fault;
– Easy integration into intra-domain network, that can be expended.

But one of the main drawbacks is considerable power loss and complexity of labels coding organization circuits and high cost of λ_k-ESR equipment. General drawback of all λ-MPLS circuits in hierarchical networks is limitation by maximum frequency of heading transfer – up to 1000 MHz [1, 3], although, this is sufficient for most problems of intra-domain usage of λ-MPLS optical switching technology.

Conclusions

The paper analyzes main problems of modern hierarchical optical networks with λ-MPLS routing. In the process of research carried out, it was revealed that main drawbacks are low speed and carrying capacity of intra-domain transfer in the networks on the base of λ-MPLS method. The method of increasing carrying capacity of hierarchical network, based on the usage of universal model of distributed λ-MPLS chains of specialized routers and switches is suggested.

Comparative analysis of λ-MPLS technology at different levels of network hierarchy with the existing technology of IP-routing is carried out , the analysis showed that at high speeds of data transfer and larger degree of network loading the value of packet delay is greatly influenced by small-size IP- packets.

Ways of optimization of hierarchical networks carrying capacity are suggested.

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