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Availability Models for Wavelength Channel Protection in WDM Ring Networks

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Introduction

The modern, industrialized societies are considerably dependent on telecommunication services. The increase in data transmission and development of Internet traffic require the high capacity transmission systems. Thanks to the development of fotonic technologies, systems are designed based on Wavelength Division Multiplexing (WDM) having high transmission speeds by a single fibber. In those networks, the service interrupt for whatever reason, caused by equipment failure, or by human factor, can cause unavailability of communication services, as well as heavy losses to the users and network operators. Therefore, the application of protection in such systems has important role for the network operators [1]. Contracts between the operators and their users are always made on the Service Level Agreement (SLA) which is very strict, as far as availability and service quality are concerned. The possibility to ensure high availability is the key one for the operators to maintain the existing and to aquire new users; this mostly reflecting in the price of their network. The operators may largely invest to equip their network with the high quality of hardware [2]. However, the quality improvement of these components beyond the present level for commercial systems is hard to achieve, and it is beyond their control. More acceptable way to ensure high availability is the use of different protection strategies. Although there are more protection strategies we shall concentrate in this work at the wavelength channel protection of WDM which is very similar to the path protection of SDH technology [3].

The network operators, upon signing a SLA contract, promise their users to ensure the high availability services. This work is finding out what is the impact of a failure on optical cables and equipment on the availability of connection. The models and analysis of different node structures are given as well as their impact on availability and the availability of node depending on the manner it is being used in the network (add, drop, pass-through). In this work we focus on the wavelength channel protection strategy, which consists of ensuring the protection channel for each working channel on the end to end basis.

Availability theory

Availability A in some system is the probability that it will be functional in given time, or it is the time relation in which the system is correct in relation to total time. Unavailability U of a system is the probability complementary to availability. At reporting about system performances, the unavailability is often expressed as a Mean Down Time (MDT) in minutes of the year

$$MDT = \frac{MTTR}{MTTR + MTTF}, \qquad (1)$$

where MTTF – Mean Time to Failure; MTTR – Mean Time to Repair [4]. In this work we suppose that MTTF for the wavelength channel is constant and independent on component ageing. MTTF= 1/λ, where λ is the intensity of failure usually expressed in FIT-a (Failure in Time); 1FIT = 1 failure in 10^9 hours.

The basic transport entity of WDM systems is a wavelength channel. This is the simplex type of connection with a standard of value between two nodes (for example, 2.5 Gb/s). The wavelength channel in an unprotected system (serial structure) generally passes through nodes, which can be optical add/drop multiplexers, optical switches and optical links. The availability of a serial structure equals to the availability product of individual components, namely:

$$A_s = \prod_{i=1}^{n} A_i \, . \qquad (2)$$

This structure is unable to restore the communication between two nodes in the case of a failure on any of components, or the connection is functional if and only if all components of the structure are correct. A substantial availability improvement can be obtained by the application of a parallel structure, by addition a protection path. It is certainly important that these two paths are completely independent, or that they do not have common components [5]. If we characterize the availabilities of working and protection path as the two completely independent elements (w and p), then the availability of such a structure is the union of two non-disjunctive events or the events which do not exclude each other because there is no complementary variable.

$$A_p = P(w \cup p)\,. \tag{3}$$

In order these two events to be mutually exclusive it is necessary to transform this union of non-disjunctive events into a union of disjunctive events. By using De Morgan's laws we obtain that the availability is

$$A = P\left\lfloor w \cup (\overline{w} \cap p)\right\rfloor. \tag{4}$$

By using the distributive law with regard to the union and section

$$A \cup (B \cap C) = (A \cup B) \cap (A \cup C)\,, \tag{5}$$

we obtain that

$$A_p = P(w \cup \overline{w}) \cap (w \cup p)\,. \tag{6}$$

Since $w \cup \overline{w} = 1$ (full set) we can write

$$A_p = P\left[1 \cap (w \cup p)\right] \tag{7}$$

and to the identity $1 \cap p = p$, so is

$$A_p = P(w \cup p)\,. \tag{8}$$

And this is actually the availability of the parallel structure. The connection availability for a wavelength channel is [7]

$$A_p = A_k = A_w + A_p - A_w A_p\,. \tag{9}$$

The connection between two nodes in a parallel structure will be incorrect if, and only if there is a failure on the working and protection path. Of course, the connection can not be established if a failure occurs in terminal nodes because they are the common components of the working and protection path.

Since the nodes are generally connected by optical links, irrespective of their architecture, in this section we shall analyze the availability for links and different node architectures.

Link availability

In order to determine the wavelength channel availability between two nodes we shall introduce some terms relative to the availability of the node and the optical link connecting two nodes. - a_{OL_i}, availability of i-th link on working path, a_{n_j}, availability of j-the node which belongs to the working path.

An unprotected link consists of the optical fiber, optical booster (a_{BOA}), amplifier (a_{OA}), line amplifier (a_{LOA}) and optical pre-amplifier (a_{OPA}). In order that the connection will be functional, all components optical link must be correct. The most often cause of an optical link failure is the breakdown of optical fibber. Since, in the case of the cable breakdown, mostly all the fibers break, we shall suppose that the failures of fiber and cable are fully dependent. Therefore, instead of the availability for fiber, we shall take the availability for cable (a_{OC}).

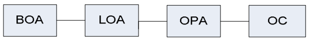

Fig. 1. Unprotected link structure

The availability of the link without the protection equals to the availability product of individual components.

$$a_{OLNP_i} = a_{BOA} \times a_{LOA} \times a_{OPA} \times a_{OC}\,. \tag{10}$$

In second instance shown in Fig. 2, two nodes are connected by two fibers belonging to the same cable.

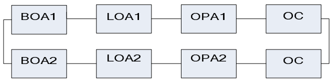

Fig. 2. Span protected link

The availability for this structure (Span Protection-SP) equals to the parallel addition of the individual branch availabilities. So it can be written:

$$\begin{aligned} a_{OL,.SP} &= a_w \cup a_p = a_w + a_p - a_w \cap a_p \\ &= a_{BOA1} a_{LOA1_1} a_{POA1} a_{OC} + a_{BOA2} a_{LOA2} a_{OPA2} a_{OC} - \\ &\quad - \left(a_{BOA1} a_{BOA2} a_{LOA1} a_{LOA2} a_{OPA1} a_{OPA2} a_{OC} a_{OC}\right). \end{aligned} \tag{11}$$

Although in the above equation's small brackets we have a product of two equal members $a_{OC} \times a_{OC}$, only one is present in the formula for availability a_{OC} because the cause of node failure is the same so we get:

$$\begin{aligned} a_{OL.,SP} &= a_{BOA1} a_{LOA1_1} a_{POA1} a_{OC} + a_{BOA2} a_{LOA2} a_{OPA2} a_{OC} - \\ &\quad - \left(a_{BOA1} a_{BOA2} a_{LOA1} a_{LOA2} a_{OPA1} a_{OPA2} a_{OC}\right). \end{aligned} \tag{12}$$

In this type of protection it is actually the protection in the case of a failure on some of the amplifiers but not the optical fibers.

In the third type of protection (route diversity-RD), the link structure is same as in span protection, in that the nodes are connected by optical fibers belonging to completely separated cables, as shown in Fig. 3.

$$\begin{aligned} a_{OL.,RD} &= a_{BOA1} a_{LOA1_1} a_{POA1} a_{OC1} + a_{BOA2} a_{LOA2} a_{OPA2} a_{OC2} - \\ &\quad - \left(a_{BOA1} a_{BOA2} a_{LOA1} a_{LOA2} a_{OPA1} a_{OPA2} a_{OC1} a_{OC2}\right). \end{aligned} \tag{13}$$

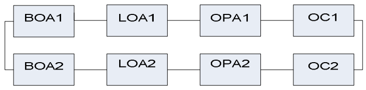

Fig. 3. Completely separated links

This type of protection protects the connection in the case of a failure on transmission equipment as well as optical cables.

Availability for different node structure

Nodes in which a wavelength channel is being dropped and added are called termination nodes. Nodes through which a wavelength channel runs from „west“ to „east“ and are located between terminal nodes are called pass-through nodes. Since the wavelength channel passes trough the different components inside these two types of nodes their availability is different: $a_{n_j t}$, terminal node is a working one [7], $a_{n_j p}$, pass-through node is working one. If all nodes of the same type are the same we have $a_{n_j t} = a_{nt}, \forall j,\ a_{n_j p} = a_{np}, \forall j.$

Node with passive components

If passive components are used, the node structure in the 1+1 wavelength channel protection are show on Fig. 4.

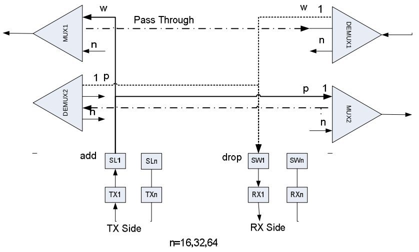

Fig. 4. Node structure for 1+1 protection

For the instance of a terminal node (bidirectional communication), the wavelength channel passes through the transmitter, divider, multiplexers, demultiplexers, switch and receiver, so that the terminal node availability for one wavelength channel is

$$a_{nt,1+1(1)} = a_{TX1} \times a_{SPL1} \times (a_{MUX1} \cup a_{MUX2}) \times$$
$$(a_{DMUX1} \cup a_{DMUX2}) \times a_{SW1} \times a_{RX1.} \tag{14}$$

In pass through nodes, a wavelength channel passes through the demultiplexers and multiplexers so the availability for pass-through nodes is

$$a_{np,1+1(1)} = a_{MUX1} \times a_{DMUX1} \times a_{MUX2} \times a_{DMUX2}. \tag{15}$$

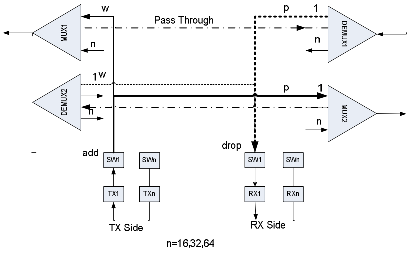

Fig. 5. Node structure for 1:1 protection

In 1:1 protection, if passive components are being used, the wavelength channel in terminal nodes passes through the transmitter, switch, multiplexers, demultiplexers, switch and receiver so that the terminal node availability for one wavelength channel and 1:1 is

$$a_{nt,1:1(1)} = a_{TX1} \times a_{SW1} \times (a_{MUX1} \cup a_{MUX2}) \times$$
$$(a_{DMUX1} \cup a_{DMUX2}) \times a_{SW1} \times a_{RX1}. \tag{16}$$

The availability for pass through nodes is same as for the 1+1 protection. The availability for all wavelength channels (n) inside a terminal node should be

$$a_{nt,1+1(n)} = a^{n}{}_{TX1} \times a^{n}{}_{SPL1} \times (a_{MUX1} \cup a_{MUX2}) \times$$
$$\times (a_{DMUX1} \cup a_{DMUX2}) \times a^{n}{}_{SW1} \times a^{n}{}_{RX1}. \tag{17}$$

Node with active components

An optical switch with add/drop possibilities is used as the active component. Fig. 6 represents an optical add/drop multiplexer (OADM) using such an optical switch.

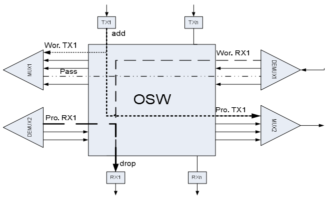

Fig. 6. Node structures with an active optical switch

In the case that the node is used as terminal one, the wavelength channel passes through the transmitter, optical switch, multiplexers, demultiplexers and receiver so the availability for one wavelength channel is

$$a_{nt,(1)} = a_{TX1} \times a_{OSW} \times (a_{MUX1} \cup a_{MUX2}) \times$$
$$(a_{DMUX1} \cup a_{DMUX2}) \times a_{RX1}. \tag{18}$$

The availability for all the wavelength channels in terminal node should be

$$a_{nt,(n)} = a^{n}{}_{TX1} \times a_{OSW} \times (a_{MUX1} \cup a_{MUX2}) \times$$
$$(a_{DMUX1} \cup a_{DMUX2}) \times a^{n}{}_{RX1}. \tag{19}$$

If the node is a pass-through one wavelength channel passes through the multiplexers and optical switch so the availability is

$$a_{np} = a_{MUX1} \times a_{DMUX1} \times a_{MUX2} \times a_{DMUX2} \times a_{OSW}. \tag{20}$$

The availability of terminal nodes is same for the 1+1 and 1:1 protection because the optical switch can act both as the divider and switch.

Availability for WDM ring

Since the installation of more SDH line systems between two nodes is very expensive, as the capacities of optical cables exhaust considerably, the need for high transmission capacity system requiring only two fibers, has arisen. Such are WDM systems based on wavelength multiplexing which uses the wavelength channel protection. Here we shall analyse the availability for WDM ring, which uses the wavelength channel protection. In this type of protection the switching is carried out on wavelength channel level so that the protection capacity is one wavelength. There are two types of protection: OCh dedicated protection ring (OCh DPRing) and OCh shared protection ring (OCh SPRing).

OCh dedicated protection ring

This type of protection requires two fibers in a ring. Each wavelength channel is being routed on the working path along one side of the ring, and the corresponding dedicated wavelength channel, along the opposite side. Bidirectional wavelength requirements are supported by two wavelength channels; one in each direction. Two types of dedicated protection are possible: 1+1 and 1:1.

In the ring network which uses the 1+1 wavelength channel protection the wavelength channel in the source node is being duplicated and concurrently delivered in both directions of the ring; working and protection [11].

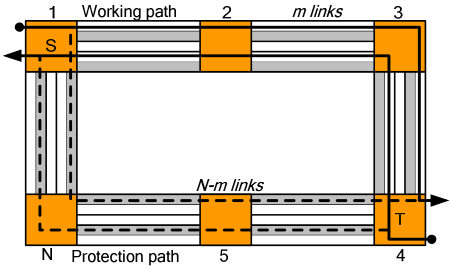

Fig. 7. 1+1 wavelength channel protection under conditions without a failure

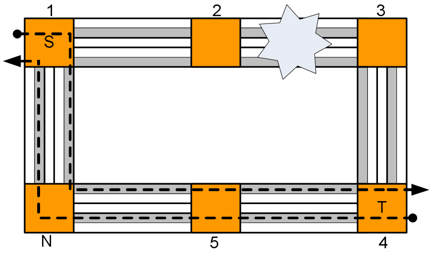

Fig. 8. 1+1 wavelength channel protection in the case of a failure on working path

Under ordinary conditions in terminal node, the receivers gets two signal copies (with a different delay) and chooses the best one. In the case of a failure on the working path, the receiver chooses the signal that it gets from the protection path. This is single-ended protection because the switching is carried out only on one (receiving) side. It is important that the working and protection path do not have common components, in order that one failure would not cause total communication break down, and this means that the component failures on the working and protection paths are fully independent.

For each wavelength channel of working path, a corresponding wavelength channel on protection path is reserved and therefore, we are talking about an 1+1 wavelength channel protection [8].

Since the wavelength channels on protection path are persevered we are talking about, so called, dedicated protection in which no active switch is required. The wavelength channels on the working and protection paths have the same wavelength but that is not a rule.

Let the network generally consist of N nodes and N links connecting those nodes [9]. If a wavelength channel on the working path P0 passes through the *m* number of optical links between terminal nodes, the availability for the working path is equal to the availability product for optical links and nodes through which this wavelength channel passes [10]

$$a_{st}(P_0) = \prod_{i,j\in P_0} a_{OL_i} \times a_{n_j} = \prod_{i\in P_0} a_{OL_i} \times \prod_{j\in P_0} a_{n_j}$$

$$= (a_{nt})^2 \times (a_{np})^{m-1} \times \left[\prod_{i\in P_0}^{m} a_{OL_i}\right]. \qquad (21)$$

In the case of a failure on the working path, the wavelength channel passes the *N-m* number of optical links and the *N-m-1* of nodes on the protection path P1.

The availability for the protection path is [10]

$$a_{st}(P_1) = \prod_{i,j\in P_1} a_{OL_i} \times a_{n_j} = \prod_{i\in P_1} a_{OL_i} \times \prod_{j\in P_1} a_{n_j} =$$

$$= (a_{nt})^2 \times (a_{np})^{N-m-1} \times \left[\prod_{i\in P_1}^{N-m} a_{OL_i}\right]. \qquad (22)$$

The availability for the wavelength channel between the s and t nodes is completely determined by these two paths, so that the availability for the wavelength channel in the case of 1+1 protection is calculated as the availability of two branches, which are fully independent:

$$A_{st}(a) = a_{st}(P_0) + a_{st}(P_1) - \left[a_{st}(P_0) \times a_{st}(P_1)\right]; \qquad (23)$$

$$A_{st}(a) = (a_{nt})^2 \times (a_{np})^{m-1} \times \left[\prod_{i\in P_0}^{m} a_{OL_i}\right] +$$

$$+ (a_{nt})^2 \times (a_{np})^{N-m-1} \times \left[\prod_{i\in P_1}^{N-m} a_{OL_i}\right] -$$

$$- \left\{ \begin{aligned} &(a_{nt})^2 \times (a_{np})^{m-1} \times \left[\prod_{i\in P_0}^{m} a_{OL_i}\right] (a_{nt})^2 \times \\ &\times (a_{np})^{N-m-1} \times \left[\prod_{i\in P_1}^{N-m} a_{OL_i}\right] \end{aligned} \right\}; \qquad (24)$$

where *a* determines the availability for optical links and nodes. Only one member $(a_{nt})^2$ is taken in the expression because the cause of node failure is the same one:

$$A_{st}(a) = (a_{nt})^2 \times \left\{ \begin{aligned} &(a_{np})^{m-1} \times \left[\prod_{i\in P_0}^{m} a_{OL_i}\right] + \\ &+ (a_{np})^{N-m-1} \times \left[\prod_{i\in P_1}^{N-m} a_{OL_i}\right] - \\ &- (a_{np})^{N-2} \times \left[\prod_{i\in P_0,P_1}^{N} a_{OL_i}\right] \end{aligned} \right\}. \qquad (25)$$

If optical links have the same length, their availability is same, i.e $a_{OL_i} = a_{OL}, \forall i.$ In this case, the availability between the s and t nodes is

$$A_{st}(a) = (a_{nt})^2 \times \left[\begin{aligned} &(a_{np})^{m-1} \times (a_{OL})^m + \\ &+ (a_{np})^{N-m-1} \times (a_{OL})^{N-m} - \\ &- (a_{np})^{N-2} \times (a_{OL})^N \end{aligned} \right] \qquad (26)$$

OCh shared protection ring

This protection also uses 2 fibers for connecting the ring nodes. It is very similar to an 1:1 protection because it does not have prereserved protection wavelength channels. The difference is that half the wavelength channels on each fiber is reserved for working traffic and the other half for protection traffic, while in an 1:1 protection all wavelength channels on a fiber are reserved for the protection, and in a situation without a failure they can be used for the subordinated traffic. Working channels in one fiber are protected by working channels in another fiber. Protection wavelength channels pass along the ring in the opposite direction than the working channels do.

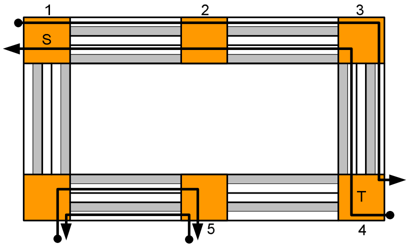

Fig. 9. OCh shared protection under conditions without a failure

When a failure damages all links between two adjacent OADMs in the ring, the protection path will be established between the source and destination OADM. When a failure occurs, the switching action is required in the source and destination OADM. However, the switching must be carried out for each damaged wavelength.

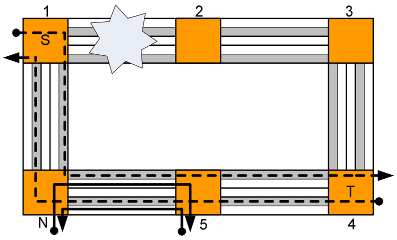

Fig. 10. OCh shared protection under conditions with a failure

From the availability aspect, the same expression applies for this type of protection as for the 1:1 dedicated protection, in that case the capacity in the ring is more efficient.

Numerical results

For availability calculation we shall use the expression by changing the nodes structure and using different optical link protections: **S**pan **P**rotection and **R**oute **D**iversity. The data is shown in Table 1 [9]. NOTE: w is the number of wavelength channels.

Table 1. Availabilty data for optical components

Component/Device	*Symbol*	*Failure*
Booster Amplifier	*BOA*	*3200*
Line Amplifier	*LOA*	*3200*
Pre - Amplifier	*POA*	*3200*
Multiplexer	*MUX*	*25xW*
Demultiplexer	*DEMUX*	*25xW*
Optical Switch	*OSW*	*1000*
Fix Transmitter	*TRX*	*186*
Tunable Transmitter	*TX*	*745*
Fix Receiver	*RX*	*70*
Tunable Receiver	*RCX*	*470*
Switch	*SW*	*50*
Splliter	*SPL*	*50*
Cable (per km)	*OC*	*100*

Table 2. Unavailability and MDT for an optical link λ =100 FIT/km

	$U\ x10^{-6}$	MDT (min/ year)
MTTR=12		
***S**pan **P**rotection*	*96.01*	*50.51*
***R**oute **D**iversity*	*0.04*	*0.02*
MTTR=21		
***S**pan **P**rotection*	*168.01*	*88.30*
***R**oute **D**iversity*	*0.13*	*0.07*

Optical link unavailability results from the above table are obtained on the assumption that the link length is 80 km and MTTR=12 hours and 21 hours. As it can be seen from Table 2, the unavailability for optical link, as expected, is substantially higher for Span Protection than it is for Route Diversity. Namely, in SP, fibers of the both paths (working and protection) belong to the same cable, so that the same cause of failure actually breaks down the entire communication between nodes and therefore, and traffic as well. It is also noticeable that the increase in time to repair considerably increases the unavailability.

Table 3. Unavailability and MDT (min/year) for a node with passive components

	$U\ x10^{-6}$		MDT	
MTTR=4 h	$\lambda = 16$	$\lambda = 64$	$\lambda = 16$	$\lambda = 64$
Terminal	*1.42*	*1.42*	*0.75*	*0.75*
Pass-through	*6.40*	*25.60*	*3.36*	*13.46*
MTTR=6 h				
Terminal	*2.13*	*2.13*	*1.12*	*1.12*
Pass-through	*9.60*	*38.42*	*5.04*	*20.18*

Table 4. Unavailability and MDT (min/year) for a node with active components

	$U\ x10^{-6}$		MDT	
MTTR=4 h	$\lambda = 16$	$\lambda = 64$	$\lambda = 16$	$\lambda = 64$
Terminal	*5.02*	*5.02*	*2.64*	*2.64*
Pass-through	*10.40*	*29.60*	*5.47*	*15.56*
MTTR=6 h				
Terminal	*7.53*	*7.53*	*3.96*	*3.96*
Pass-through	*15.60*	*44.40*	*8.20*	*23.34*

Unavailability for optical nodes with passive and active components was calculated for the instances of 16 and 64 wavelengths, at a time to repair of 4 and 6 hours. It can be seen from Tables 3–4, the unavailability for terminal nodes is almost independent on the number of wavelengths, because the multiplexers are in parallel connection for both types of protection (SP and RD).

In pass-through nodes the increase in the number of wavelengths has an essential impact on the unavailability increase due to serial connection of the multiplexers (for PC and MTTR=4 hours this increase is about 4 times; for AC it is about 2,84 times).

The highest unavailability is in SP where MTTR=6; 21 because the optical link impact in this type protection is dominant on total unavailability. The reason for this it that, for optical cable breakage, communication between terminal nodes is being lost for as long as the very same has not been repaired, because both the working and protection are connected to the fibers of same cable (for N=16 an increase in time to repair from 4 to 12 to 6 and 21 increases the SP unavailability for 59%).

Conclusion

This work's result analysis shows Span Protection has substantially higher unavailability than Route Diversity because both directions are connected to the optical links whose fibers belong to the same cable. In RD protection the working and protection paths are completely independent and so such a system is only unavailable in the case of a simultaneous failure on both paths (working and protection) and in the case of a failure in terminal nodes.

By the analysis it is also obtained that the numbers of wavelengths, as well as nodes build-up of active and passive components, do not have a big impact on WDM ring availability, irrespective of the type of protection. It is also established that the impact of optical link time to repair is considerable, while in RD more considerable is the impact of device repair, for the reason that the RD nodes availability has a dominant impact on total unavailability. A WDM ring availability improvement can be achieved by the reduction of time to repair both the optical links and devices. That requires a better maintenance and teams organization.

However, a considerable availability improvement can be achieved by the ring networks construction whose working and protection path have no common components, and they are fully separated, thus offering high availability services to the users.

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I. Rados. Availability Models for Wavelength Channel Protection in WDM Ring Networks // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 8(88). – P. 81–86.

Modelling and availability for the ring networks based on WDM (Wavelength Division Multiplexing) technology with wavelength channel protection mechanism was analyzed. The basic availability concepts are introduced, with particular focus on parallel ring network structure. An analysis of different active and passive nodes and their availability is carried out. The availability for optical link, especially the Span Protection and Route Diversity, is analysed. The wavelength channel protection principles being used in WDM ring networks are explicated: OCh dedicated and OCh shared protection. The availability models for a WDM ring using these types of protection and the impact of availability for nodes and optical links on the entire ring availability is given. Intensity of failures and mean time to repair values are taken from literature. We assumed WDM system with 16 and 64 wavelengths and 2.5 Gb/s as the basic capacity being carried by the wavelength channel was used. Ill. 10, bibl. 11 (in English, summaries in English, Russian and Lithuanian).

И. Радос. Модели доступности для защиты каналов кольцевых сетей WDM // Электроника и электротехника. – Каунас: Технология, 2008. – No. 8(88). – P. 81–86.

Анализируется моделирование и доступность кольцевых сетей, основанных на WDM (мультиплексирование длины волны) технологии с механизмом защиты канала. Приведены основные понятия доступности, отдельно акцентируя параллельную кольцевую структуру сети. Выполнен анализ различных активных и пассивных узлов и анализ их доступности. Анализирована доступность оптической связи, используя разные механизмы защиты. Даны экспериментальные результаты испытания оптических каналов, когда в WDM системе используются 16 и 64 длины волн, а пропускная способность каждого канала 2,5 ГБ/с. Ил. 10, библ. 11 (на английском языке; рефераты на английском, русском и литовском яз.).

I. Rados. Žiedinės struktūros WDM tinklų kanalų pasiekiamumo apsaugos modeliai // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 8(88). – P. 81–86.

Analizuotas WDM technologijos pagrindu sudarytų žiedinės struktūros tinklų modeliavimas ir pasiekiamumas, naudojant kanalų apsaugos mechanizmus. Pateiktos bazinės pasiekiamumo koncepcijos, daugiau analizuojama lygiagreti žiedinio tinklo struktūra. Analizuoti skirtingi iš aktyvių ir pasyvių komponentų sudaryti mazgai bei jų pasiekiamumas. Daugiau dėmesio skiriama optiniams kanalams, analizuojant „Span Protection“ ir „Route Diversity“, skirtinę OCh ir paskirstytąją OCh apsaugą. Pateikti šių apsaugos tipų modeliai, nagrinėta jų įtaka mazgų, optinių kanalų ir viso žiedo pasiekiamumui. Gedimų intensyvumo ir vidutinio remonto trukmės duomenys paimti iš literatūros. Tirta WDM sistema, naudojanti 16 ir 64 bangų ilgių kanalus, kiekvienam kanalui tenkantis pralaidumas – 2,5 Gb/s. Il. 10, bibl. 11 (anglų kalba, santraukos anglų, rusų ir lietuvių k.).

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