Suggestions for Availability Improvement of Optical Cables

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Abstract – **This article analyzes suggestions for availability improvement of optical cables. There are specially analyze two different suggestions: decrease numbers of failures respectively increase mean time to failure and decrease mean time of repair optical cable. The date, which used in this article, are results of attended of failure rate during lasting several years exploitation of optical cables in SDH network HPT d.o.o. Mostar. Based on the data about failure rates, unavailability and mean down times of optical cables are made the suggestions for availability improvement.**

Keywords – **failure rate, availability, mean down time**

I. Introduction

The introduction of new services and the need of high quantity of data transmission require the high capacity transmission systems (SDH, WDM). One of the important elements of the transmission system is transmission media – in this article it is optical cable. The failures – interrupts the communication between great number of users – are making great losses for network operators [1]. Therefore, the availability performances of optical network greatly depend on availability of optical cables.

The HPT Mostar began whit installation and using of the optical cable as a transmission media in spring 1994. Ever since the optical cables have become the main transmission media at all network levels. The date about failure rate, which is analyzed, refereed to the two periods: from spring 1994. to the May 01, 1999 – we did not application suggestions for availability improvement of optical cable – and from May 01, 1999 to May 01, 2001 – we application one of the suggestions for availability improvement of optical cable. We will explain after in the article how we decided which suggestions we application on our network. Based on collected data we are analyzed the availability performances on which based the availability improvement is achieved.

II. On Availability in General

Availability A of some system in the time frame is defined as a ratio of time during which the system is functional in relation to the total operational time [2], i.e. it's probable that the system is functional in some time frame.

$$A = \frac{MTTF}{MTTF + MTTR} \tag{1}$$

where, $MTTF$ (Mean Time To Failure) is mean time till the failure occurs and $MTTR$ (Mean Time To Repair) mean time of repair.

$$MTTF = 1/\lambda \tag{2}$$

where λ is the failure rate defined as the number of failures per time unit.

$$1\ FIT\ (\text{Failure in Time}) = 1 \text{ failure per } 10^9 \text{ hours}$$

$$\lambda = \frac{m}{MT} \tag{3}$$

where n is the number of failures over monitoring time, M the length of installed cables in km and T monitoring period in hours.

For the entire optical network, comprising L kilometers of cables, mean time to failure ($MTTF$) is obtained as follows:

$$MTTF_{\text{network}} = \frac{1}{\frac{\lambda_{\text{cable}}}{\text{km}} L[\text{km}]}. \tag{4}$$

Unavailability U is probability complementary to availability [3], i.e.

$$U = 1 - A = \frac{MTTR}{MTTF + MTTR} = \lambda\, MTTR. \tag{5}$$

In reporting about system/network performances, unavailability U is often expressed as MDT (Mean Down Time) in minutes per year [3], i.e.

$$MDT = 3656024U \text{ [min/year]}. \tag{6}$$

III. Failure Analysis and Availability Calculation

In order to calculate the availability of optical cables, data on failures and time to repair of optical cables are used. The collected data referred to the period from spring 1994 to May 01, 1999 and period from May 01, 1999 to May 01, 2001. All cables are installed sub-surface, in polyethylene pipes and above them a warning tape was installed as a supplementary way of protection. Fibers of all cables are standard, single-mode with a diameter of 9/125 μm for the use of 1310 nm and 1550 nm wavelengths.

According to the collected data the main cause of most failures is outside interference (86.48%), where digging participates in 72.97% of cases [3]. The vehicle owing to the improper depth of installed cable causes two failures (5.40%) and the fire causes three failures (8.10%). Four failures (10.80%) are the consequence of the planned works by the HPT d.o.o. Mostar. These failures lasted relatively a short time because of previously well done preparations.

From the point of view of the optical failures availability we distinguish [4]:

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- failures which break individual fibers in the cable, if there is no automatic protection, the operator has manually to direct the traffic to the correct fibers or to repair the faulty once,
- failures which simultaneously break all fibers in the cable, unless the network is ring, the operator has to repair all fibers in the cable with no regard to the existence of some protection mechanisms (optical modules). According to the collected data in 100% of causes happens the break of all fibers, either caused by digging or by fire or by vehicle.

Generally, two measures to repair are being used [2]:

- temporary repair time,
- permanent repair time.

Temporary repair time is the time needed for service restoration after the failure. This time to repair includes:

- time needed to report the failure to the maintenance team and their arrival to the telecommunication center,
- time needed for the preparation of splicing material (cable) and vehicles, - way to the failure location,
- laying of the new piece of cable (if needed) and its splicing,
- final measurements.

Table 1. Monitoring period, length and number of failures of optical cables

Monitoring period	Length (km)	Number of failures
spring 1994 – May 01, 1999	795	23
May 01, 1999 – May 01, 2001	456	14
spring 1994 – May 01, 2001	1251	37

Table 2. Failure causes of optical cables until May 01, 2001

Failure causes	No. of repor. failures	Relativ. % failures
Digging	27	72.97
Installat./workman errors	1	2.70
Defective connector	0	0.00
Fire	3	8.10
Vehicle	2	5.40
Fibers arrangement	0	0.00
Cable displacement	4	10.80
TOTAL:	37	100.00

According to the experience, the time needed to report to the maintenance team and their arrival to the telecommunication center is less than an hour. As there is no data on exact distance from the maintenance centers to the failure location, the time needed to arrive to the failure location is no special analyzes. But when the distance from the maintenance team center to the failure location is short, the influence of the arrival time to the failure location in relation to the total time to repair is insignificant.

The greatest influence on the time to repair has the type of failure, for example: difficult access to damaged cable, necessity for digging and installing the new piece of cable, cable capacity and splicing of fibers of different manufacturers, unfavorable weather conditions.

If only two fibers on one cable are actively used, regard to the availability there are exist two cases:

- repair of active fibers wherewith the system becomes available,
- repair of all fibers in the cable.

On the area covered by telecommunication network of HPT d.o.o. Mostar actively exist more transmission systems via the single mode cable, so the time needed to repair all fibers in the cable (or in more cables) is taken for the calculation of the time to repair.

Permanent repair time includes, in addition, final storage of new splicing closures, final construction works and final protection of a new cable segment.

In this article the temporary repair time is used as mean time to repair for the availability calculation owing to its influence on availability.

Until May 01, 1999 HPT d.o.o. Mostar had only one team with three members for maintains of optical cables. Two members out of three do the splicing and the one do finally measurements. The maintenance team had only one splicer and one OTDR, what practically mean that they be able do splicing only on one side of optical cable (if is necessity for installing the new piece of cable). It was 60% of the exact documentation of installing optical cables. Average time for repair during this period was 15.70 hours.

From May 01, 1999 HPT d.o.o. Mostar took precautions with aim to decrease average time to repair of optical cable (detail explanation in chapter 4). The results of this precaution were decrease average time to repair on 13.43 hours.

That we on the best way see influence to decrease average time to repair on availability of optical cables in this chapter we are presume that no decrease its that mean we are use for calculation average time to repair 15.70 hours.

Unavailability of optical cables per km is obtained as a product of failure rate per km of cable and the mean time to repair as shown in table 3.

Table 3. Failure rate (λ), unavailability (U) and mean down time (MDT) calculated for optical cables

λ (FIT/km)	$U \times 10^{-5}$	MDT (min/year)
460.61	0.72	3.80

For the unavailability calculation of the optical cable besides the mean time to repair and failures rate per km it is necessary to know the failure rates of the splices on the fiber and failure rate of connectors on the optical distribution frame. Data on failure rates of splices (30 FIT) and connectors (100 FIT) are taken from the [5] and [6]. The total length of the cable stage consists of delivered cable from factory with an avarage length of 4 km. According to this length the number

Table 4. Failure rate (λ-total), unavailability (U) and mean down time (MDT) calculated for different optical link lengths

Length (km)	No. of splices	No. of connect.	λ-total (FIT)	$MTTR$ (h)	$U \times 10^{-5}$	MDT (min/year)
20	5	2	9562.20	15.70	15.01	78.89
40	10	4	19124.40	15.70	30.02	157.78

of splices is calculated as:

$$\text{Length of cable}/4.$$

The number of connectors on the optical distribution frame is 2 for the average stage length which is used in this calculation.

The result analysis in table 4 shows that unavailability increase almost linearly to the cable length and depends on failure rate and mean time to repair of optical cables. For SDH network HPT d.o.o. Mostar, mean time to failure ($MTTF$) is obtained as follows:

$$MTTF_{\text{network}} = \frac{1}{460.61\,1251\,\text{failures}}\,\frac{h}{} = 1735h \approx 73\ \text{days}$$

IV. Suggestions for Availability Improvement

From the availability expression (1) can be seen that the availability depends on the mean time between failures and the mean time to repair of optical cables. Availability improvement can be obtained by increasing the mean time to failures and decreasing the mean time to repair of optical cables [4].

A. Increasing of mean time to failure

The increase of mean time to failures, relatively, the decrease of the number of failures can be achieved by preventive protection of optical cables against digging and by using the surveillance system for preventive maintenance. As most failures on the optical cables are caused by digging it is necessary to attract special attention to it. Although most countries have laws for preventive protection of underground cables there are still unsatisfactorily defined punishments (fees) for their infringements (digging without previous consent). The law must have to most rigid punishments (invitation prior to digging). While digging belong to the category of "instantaneous" breaks, the others belong to the category "preventive" because they are caused by complete loss of cable characteristics owing to the outside interference.

In our country still no have law about preventive protection of underground cables, what is a possible conclude on the base of number of failure during both monitoring periods, most of the failures were caused digging without previous consent and transgressor has no adequate punishment. That we are show influence mean time to failure on availability we will suppose that we already have the legal regulations regarding the protection of underground cables during the failure monitoring period and that, through change of that law, the mean time to failures increased from 73 to 84 days, which means that the number of failures decreased from 37 to 32, representing a decrease of about 13%, and that the mean time to repair remained same, i.e. 15.70 hours. As the failure rate is just proportional to the number of failures, so, decreasing the number of failures also decreases the failure rate by 13.5% or to 398.37 FIT.

As seen in the Table 5, the decrease of the number of failures resulted in the availability improvement, relatively, the decrease of MDT, for example, for $d = 20$ km – from 78.89 to 68.64 min/year or by 12.99%. Surveillance system for preventive maintenance can foresee the possible failure location using the metal protective layer on the cable as a sensor. Surveillance system alarms when the entirety of the outer sheath or the splicing point is being breaked, indicating that potential failure should be removed. As optical cables installed within the HPT d.o.o. Mostar have been exploited a short time (the first one about seven years), there were no deterioration as yet of the cable characteristics caused by the outside interference. For the preventive failure protection against outside interference (long-term exploitation) it will be necessary to install the surveillance system in order to foresee a failure. Costs for installation of such a system would be slight compared to with failure losses on the cable.

Table 5. Failure rate (λ-total), unavailability (U) and mean down time (MDT) calculated for different optical link lengths ($n = 32$ failures)

Length (km)	No. of splices	No. of connect.	λ-total (FIT)	$MTTR$ (h)	$U \times 10^{-5}$	MDT (min/year)
20	5	2	8317.40	15.70	13.06	68.64
40	10	4	16634.80	15.70	26.12	137.28

B. Decreasing of mean time to repair

From the unavailability expression can be seen that availability depends on the mean time to repair. In order to decrease the $MTTR$ it is essential to have a maintenance plan which should contain the following components [4]:

- exact documentation,
- maintenance team,
- training,
- equipment,
- plan of action,
- practice,
- continued process of improvement.

Exact documentation on optical cables is one of the most significant components for diminishing the $MTTR$. It includes: cable traces, number of failures in cable, fibers attenuation, splicing points, cable lengths, trace marking and outer-metal shield condition. Additional 34% of documentation made during period from May 01, 1999 to May 01, 2001, that mean than till now we made documentation for 94% of installing optical cable. Also it procured one mobile computer for frequent modification and bring up to date. Only two persons have access to that base and they are responsible

for its processing. Besides the exact data base for diminishing the $MTTR$ it is necessary to exactly know where are the tools and material needed to repair, as well as the key to the entrance of the building. Plan of action contains instructions on who is calling whom and when, as well as the numbers of fixed and mobile telephones. Now, maintenance team has seven members: five on the failure location and two at terminals (one in each). Four members out of five do the splicing (two teams of two members) and the fifth have the radio connections with the members at terminals.

Maintenance staff has to know to use the splicers and measuring equipment. Owing to the ever-improving measuring and connecting equipment for different types of cables, regular training of the maintenance team is very important because each improvement which leads to diminishing the time to repair increases the availability of optical cables. In HPT d.o.o. Mostar they have training two times a year at least in order to acquire new knowledge. Training in the field is more purposeful measure than the classroom teaching. Well planned and sudden exercise is the best way of the emergency staff training (one per year). The aim of each exercise is to achieve better results each time.

Quantity and kind of equipment depend on geographical spreading, network size, and the number of skilled staff. If network is too large and geographically spread there must be more maintenance teams. As network of HPT d.o.o. Mostar no geographically spread, for the now is sufficient one maintenance team of optical cable. Our maintenance team has one reflectometer (OTDR) for measuring at 1310 and 1550 nm, two splicers with tools (cutter, air, screwdrivers...), optical power meter, voltmeter and the car.

Using above mentioned suggestions, the $MTTR$ of the cable is obtained to 13.43 hours. The availability would also be improved considerably, as shown in table 6.

Table 6. Failure rate (λ-total), unavailability (U) and mean down time (MDT) calculated for different optical link lengths ($MTTR = 13.43$ h)

Length (km)	No. of splices	No. of connect.	λ-total (FIT)	$MTTR$ (h)	$U \times 10^{-5}$	MDT (min/year)
20	5	2	9562.20	13.43	12.84	67.48
40	10	4	19124.40	13.43	25.68	134.97

In the concrete, the $MTTR$ decrease of 14.45% results in the availability improvement of 14.46% or to, the decrease MDT from 78.89 to 67.48 min/year.

Every greatest availability improvement would be achieved by the simultaneous decrease of the number of failures (32) and the decrease of the mean time to repair of the cables (13.43 hours), as shown in following table 7. In the concrete, mean down time of failure is decrease for 25.57%, or to decrease from 78.89 to 58.71 min/year.

Table 7. Failure rate (λ-total), unavailability (U) and mean down time (MDT) calculated for different optical link lengths ($n = 32$ failures, $MTTR = 13.43$ h)

Length (km)	No. of splices	No. of connect.	λ-total (FIT)	$MTTR$ (h)	$U \times 10^{-5}$	MDT (min/year)
20	5	2	8317.40	13.43	11.17	58.71
40	10	4	16634.80	13.43	22.34	117.42

V. Conclusion

Data on failures and time to repair, which are analyzed in this article, refer to the 7 years exploitation of optical cables within the HPT d.o.o. Mostar transmission network. The analysis show that the most frequent cause of the optical cables break is digging (72.97%) and regardless to the break cause there has been breaks of all fibers in the cable. The analysis of temporary repair time shows that it mostly depends on the type of failure and cable capacity. Availability improvement of optical cables can be achieved by increasing of mean time to failure, relatively, decreasing the number of failures as the most frequent case of break, and decreasing the mean time to repair. The law on underground cables protection and monitoring system for preventive maintenance would be the cause of decreasing the number of failures. The mean time to repair cable is decreased considerably by using the plan of maintenance. An approximate unavailability can be used to evaluate availability of different structures.

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