Regular paper

Influence of common path on availability of ring network

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Abstract—This paper analyses availability of the ring network which uses the path protection switching (sub-network connection protection – SNCP). Influence of the common path on the ring network availability is analyzed. Data regarding failures of optical fibre cables and equipment used for calculations have been obtained during years-long observation of SDH network in HT Mostar as well as from manufacturers.

Keywords—availability, failure rate, protection, ring network, SDH network.

1. Introduction

Modern industrialized societies are considerably dependent on telecommunication services. Interruption of service for any reason, be it equipment failure or human factor, can cause isolation in telecommunications sense as well as great losses for users and network operators. Hence, "survival" of the transmission network in the conditions of failure and mistake, becomes a primary task of network operators. In synchronous digital hierarchy network (SDH), more standardized mechanisms that provide "survival" of transmission network, are predicted [1]. One of these mechanisms, "path protection", will be analyzed in this paper.

Ring structure, which provides two separated paths inside the ring, is particularly interesting. However, in real networks there are cases when paths inside the ring structure are not completely physically separated although they constitute the logical ring. In those cases the failures cannot be considered statistically independent. This is particularly related to the urban environment where it is difficult to obtain permission for the construction of another optical cable duct, so both working and protection paths inside the ring use may fibres in the same cable. This paper will provide a precise analysis of the influence of the common path on availability of 2 Mbit/s channels between two nodes inside the ring structure.

2. On availability in general

The availability $A(t)$ is defined as the probability that the system is operating at a specified point of time t [2]. As a more useful measure, availability A is determined as the ratio between the total time of failure-free operation and the total monitoring time:

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

where $MTTF$ (mean time to failure) is mean time till the failure occurs and $MTTR$ (mean time to repair) a mean time of repair.

A common unit related to availability and widely used in networking is the FIT (failures in time), where 1 FIT corresponds to 1 failure in 10^9 hours. This measure has some relevance to availability analysis that lies in the fact that the FIT value can be used to calculate the mean time to failure (in hours) of a component as follows:

$$MTTF = \frac{10^9}{FIT}\,. \qquad (2)$$

Unavailability U is probability complementary to availability [3], i.e., $U = 1 - A$. When reporting system/network performance, unavailability U is often expressed as MDT (mean down time) in minutes per year [min/year], i.e.,

$$MDT = 365 \cdot 60 \cdot 24 \cdot U\,. \qquad (3)$$

As SDH network generally consists of cable sections and nodes, optical fibre failure rate is calculated separately from node failure rate. Optical fibre failure [4] rate λ per km of installed cable per year [1/hkm] is calculated according to the equation

$$\lambda = n / M \cdot T\,, \qquad (4)$$

where n is a number of failures over monitoring time, M the length of installed cable in km and T monitoring period in hours. Failure rate of individual modules that make the node (add/drop multiplexer) is received from the manufacturer.

Availability of the series structure which includes n elements (Fig. 1) is simply the product of their individual availabilities:

$$A_s = A_1 \cdot A_2 \cdot \,\ldots\, \cdot A_n = \prod_{i=1}^{n} A_i\,. \qquad (5)$$

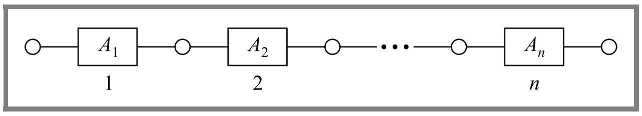

Fig. 1. Series structure from n elements.

As the availability equation shows, the failure of any element causes unavailability of the whole structure.

Generally, for parallel structure of n branches (Fig. 2a) availability is

$$A_p = 1 - \prod_{i=1}^{n} (1 - A_i)\,. \qquad (6)$$

Since, two branches (working and protection ones) are needed for the "protection path" mechanism, we are going to analyze parallel structure availability as in Fig. 2b, reflected in the following formula:

$$\begin{aligned} A_P &= 1-[(1-A_a)(1-A_b)] \\ &= 1-(1-A_a-A_b+A_aA_b) \\ &= 1-1+A_a+A_b-A_aA_b \\ &= A_a+A_b-A_aA_b\,. \end{aligned} \tag{7}$$

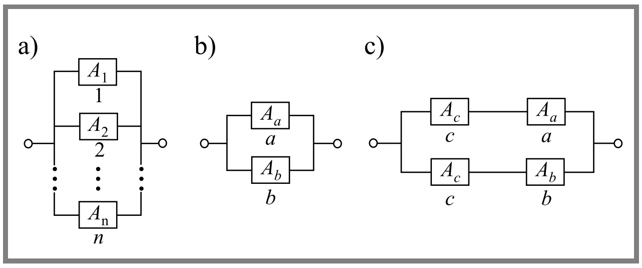

Fig. 2. Parallel structure of (a) n branches; (b) two branches; (c) two branches with common element one.

If we add to each branch the same element c, but in fact two elements of common section, whose failures are mutually completely dependent (Fig. 2c), availability of such a structure is a union probability of non-disjunctive events. Assuming that failures on network sections which are physically separated are mutually independent, we have

$$\begin{aligned} A_{cp} &= p\big[(c\cap a)\cup(c\cap b)\big] \\ &= p\big[c\cap a\big]+p\big[c\cap b\big]-p\big[(c\cap a\cap c\cap b)\big] \\ &= p\big[c\cap a\big]+p\big[c\cap b\big]-p\big[(c\cap a\cap b)\big] \\ &= A_cA_a+A_cA_b-A_cA_aA_b\,. \end{aligned} \tag{8}$$

As the above equation shows, the failure on the c element results in reduction of parallel structure availability, because c is a common element for both branches.

3. Protection path mechanism in the ring network

In a network, using the protection path (SNCP ring) mechanism, signal in the source node is transmitted in both ring directions, and a higher quality signal is chosen on the destination source input. The path the transmission signal passes through during its normal operations is called the working path (P_0), and the path the signal passes in case of failure on its working path is called protection path (P_1) [5].

We assume that the network consists of N nodes and N cable sections linking those nodes. In order to determine availability of signal we will introduce the expressions related to availability of node and availability of cable section between two nodes:

- a_{f_i}, availability of i-cable section of working path;
- a_{n_j}, availability of j-node which belongs to the working path.

Nodes in the ring in which transmission signal is extracted and added are called "termination" nodes (s and t in Fig. 3). Nodes in the ring between termination nodes the signal only passes through from the "east" to the "west" side, are called "through" (transit) nodes. Since transmission signal passes through different components inside those two node types, their availability is different:

- a_{n_jt}, termination node is working;
- a_{n_jp}, transit node is working.

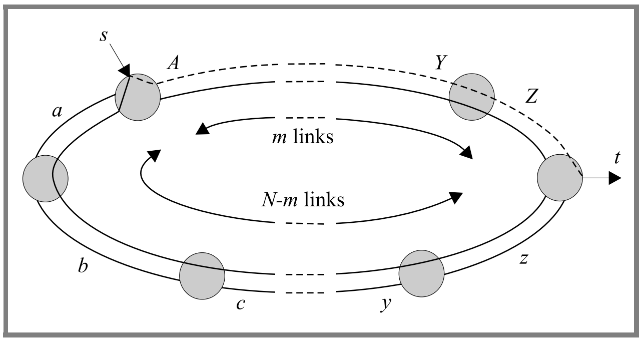

Fig. 3. Path protection in the ring network.

If all nodes of the same type are equal, then

$$a_{n_jt}=a_{nt},\ \forall j\,,$$

$$a_{n_jp}=a_{np},\ \forall j\,.$$

If transmission signal on the working path P_0 passes m cable sections between termination nodes, availability of the working path is equal to the product of all nodes and cable sections availability on that path:

$$\begin{aligned} a_{st}(P_0) &= \prod_{i,j\in P_0} a_{f_i}a_{n_j} = \prod_{i\in P_0} a_{f_i}\prod_{j\in P_0} a_{n_j} \\ &= a_{nt}^2\,a_{np}^{m-1}\prod_{i\in P_0}^{m} a_{f_i}\,. \end{aligned} \tag{9}$$

In case of failure on the working path, transmission signal passes $N-m$ cable sections and $N-m-1$ on protection path P_1 (Fig. 4).
Availability of the protection path is

$$\begin{aligned} a_{st}(P_1) &= \prod_{i,j\in P_1} a_{f_i}a_{n_j} = \prod_{i\in P_1} a_{f_i}\prod_{j\in P_1} a_{n_j} \\ &= a_{nt}^2\,a_{np}^{N-m-1}\prod_{i\in P_1}^{N-m} a_{f_i}\,. \end{aligned} \tag{10}$$

Availability of the transmission signal between s and t nodes is completely defined with these two paths, so the

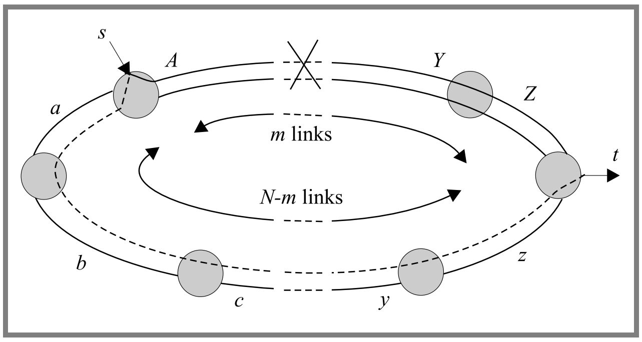

Fig. 4. Path protection in the ring network.

availability of the ring with path protection mechanism A_{st}, with completely independent paths is calculated as the availability of the parallel structure:

$$A_{st}(a) = a_{st}(P_0) + a_{st}(P_1) - \left[a_{st}(P_0)\, a_{st}(P_1)\right]$$

$$A_{st}(a) = a_{nt}^2\, a_{np}^{m-1} \prod_{i \in P_0}^{m} a_{f_i} + a_{nt}^2\, a_{np}^{N-m-1} \prod_{i \in P_1}^{N-m} a_{f_i}$$

$$-a_{nt}^2\, a_{np}^{m-1} \prod_{i \in P_0}^{m} a_{f_i}\, a_{nt}^2\, a_{np}^{N-m-1} \prod_{i \in P_1}^{N-m} a_{f_i}\,, \qquad (11)$$

where a denote the set of fibre and node availabilities. Although the equation in the big bracket contains a product of multiplication of two equal parts $(a_{nt})^2 \cdot (a_{nt})^2$, only one is taken for availability $(a_{nt})^2$ because the cause of node failure is the same and we obtain:

$$A_{st}(a) = a_{nt}^2 \left(a_{np}^{m-1} \prod_{i \in P_0}^{m} a_{f_i} + a_{np}^{N-m-1} \right.$$

$$\left. \times \prod_{i \in P_1}^{N-m} a_{f_i} - a_{np}^{N-2} \prod_{i \in P_0, P_1}^{N} a_{f_i} \right). \qquad (12)$$

If we suppose that two cable sections have the same length, then the availability of each is the same, i.e.,

$$a_{f_i} = a_f\,, \forall i\,.$$

In this case availability between s and t nodes is:

$$A_{st}(a) = a_{nt}^2 \left(a_{np}^{m-1}\, a_f^m + a_{np}^{N-m-1} \right.$$

$$\left. \times\, a_f^{N-m} - a_{np}^{N-2}\, a_f^N \right). \qquad (13)$$

If there is one common part of the path then the availability equation should include the availability of this part, and hence we have

$$A_{st\,cp}(a) = A_{cp}\, a_{nt}^2 \left(a_{np}^{m-1} \prod_{i \in P_0}^{m} a_{f_i} + a_{np}^{N-m-1} \right.$$

$$\left. \times \prod_{i \in P_1}^{N-m} a_{f_i} - a_{np}^{N-2} \prod_{i \in P_0, P_1}^{N} a_{f_i} \right), \qquad (14)$$

where A_{cp} is availability of the common path.

4. Analysis of the common path influence on availability

Availability analysis will be performed on the ring-shaped SDH network consisting of different numbers of nodes, assuming equal distances between nodes (20 and 30 km). Availability calculation was performed for 2 Mbit/s link between two nodes, assuming that the paths are completely independent and that there is one common path of different length. Availability value of "termination" and "through" (transit) nodes was calculated on the basis of data collected during system operation ($MTTR$ = 6.58 hours) and data on individual equipment module failure rate, provided by the manufacturer (Table 1).

Table 1
Unavailability and MDT for termination and transit nodes

Unavailability	U $[\times 10^{-5}]$	MDT [min/year]
Termination node	0.113	0.69
Transit node	7.385	38.82

As shown in Table 1, the termination node has much smaller unavailability than transit node because it has redundancy of all cards. With transit node the signal passes through from "east" to the "west" side, resulting in serial structure which is very sensitive to failures of individual elements.

Average failure rate for fibre optic cables is calculated on the basis of the number of failures (29) along the 795.135 km of installed cables during six years' period – see Table 2.

Table 2
Failure rate, unavailability and MDT for fiber optic cables

λ [FIT/km]	U $[\times 10^{-5}]$	MDT [min/year]
693.91	1.30	6.86

We shall first calculate the availability of the ring network consisting of different number of nodes, assuming completely independent paths and equal distances among nodes (20 km). As we can see in Table 3, with lesser number of nodes and consequently shorter total length of working path, the influence of node availability on total availability between source and target nodes is dominant. It results from the fact that in total availability, with, e.g., $N = 6$ nodes

Table 3
Unavailability and MDT for ring-shaped SDH network

Nodes	6	8	10	12	14
U $[\times 10^{-6}]$	3.34	3.95	4.75	5.74	6.91
MDT [min/year]	1.76	2.08	2.50	3.01	3.63
Cable [%]	20.64	32.19	42.76	51.73	59.05
Node [%]	74.36	67.81	57.24	48.27.	40.95

the influence of source and target node availability is prevalent with no less than 74.36% share. With increasing number of nodes and total length of the working path, the cable influence becomes dominant ($N = 14$, cables share: 59.05%).
If distance between nodes is increased to 30 km (still with completely independent paths) there is an almost linear increase of mean time to failure ($N = 10$, MDT increases for approximately 30%; $N = 12$, MDT increases for approximately 33%).

Table 4
Unavailability and MDT for ring-shaped SDH network ($d = 30$ km)

Nodes	6	8	10	12	14
U [$\times 10^{-6}$]	4.05	5.23	6.76	8.65	10.90
MDT [min/year]	2.13	2.75	3.56	4.55	5.73
Cable [%]	34.42	48.69	59.77	67.99	74.03
Node [%]	65.58	51.31	40.23	32.01	25.97

The results given in Table 4 show that the influence of node availability has decreased and the influence of cables on total availability has increased, since total length of the working path has increased. If we assume that there is 1 km of the common path, then the availability between source and target nodes is slightly greater, as seen in Table 5.

Table 5
Unavailability and MDT with 1 km of common path ($d = 20$ km)

Nodes	6	8	10	12	14
U [$\times 10^{-5}$]	1.64	1.70	1.78	1.87	1.94
MDT [min/year]	8.62	8.94	9.36	9.88	10.24
Cable [%]	83.80	84.22	84.71	85.25	85.82
Node [%]	16.20	15.78	15.29	14.75	14.18

Existence of only 1 km of the common path (e.g., $N = 8$, $d = 20$ km) increases mean down time by 429.81% or from 2.08 min/year (completely independent paths) to 8.94 min/year. Also, the influence of cable availability in total availability between two nodes becomes dominant (84.22% of cable availability, 15.78% of node availability). If for $d = 30$ km we assume 1 km of the common path (Table 6), the influence of cable availability on total availability becomes even more dominant ($N = 8$, cables 85.32%, nodes 14.68%). The result given in Tables 5 and 6 show that the common part of the path has the greatest impact on total availability between two nodes. For $N = 10$ and $d = 20$, 1% of the common path (1 km) in relation to total length of the working path gives about 73% of total availability. With $N = 10$ and $d = 30$ this impact is slightly less (about 66%), since the share of this part of the path on total length of the working path is smaller (0.66%).

Table 6
Unavailability and MDT with 1 km of common path ($d = 30$ km)

Nodes	6	8	10	12	14
U [$\times 10^{-5}$]	1.71	1.82	1.98	2.17	2.39
MDT [min/year]	8.99	9.61	10.42	11.41	12.59
Cable [%]	84.47	85.32	86.26	87.23	88.18
Node [%]	15.53	14.68	13.74	12.77	11.82

Although there are only two cables in the same trench on the common path, during the calculation we used only the availability of one cable because, on the basis of the analysis of failure situations in HT Mostar that have been done so far, both cables are always cut during failures. The main cause of optical fibre cable cuts is digging.

5. Conclusion

The results obtained in this analysis show that in ring networks with small number of nodes and completely independent paths, the nodes (particularly the termination ones) have a greater impact on total availability than the cables since the total length of working path is small and the availability of parallel structure is very close to unity. The increased distance between the nodes, and consequently the total length of the working path, leads to increased mean time to failure, and thus greater impact of cables on total availability of the ring network.
Further on, the availability of the ring structure mostly depends on the existence of the common path for working and protection directions. Very short common sections significantly reduce availability between two nodes in the ring structure. Negative influence of the common path is clearly shown in the equation for availability of the ring structure $A_{st\,cp}$ because, if $A_{cp} = 0$ (common factor of the equation), then the communication between two nodes is broken. Improved availability can be achieved with total independence of the working and the protection paths, which means that routing of working and protection path in the same cable or trench, must be avoided.

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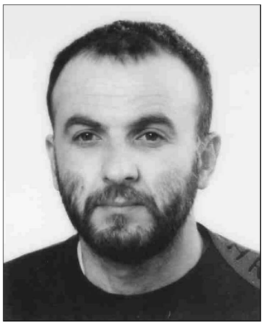

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