Reliability Assessment of Rings and \( p \)-Cycles in DWDM Networks

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Abstract— Interesting and promising recovery techniques suited for the Next Generation Internet are studied: traditional protection rings and the novel, preconfigured protection cycles (\( p \)-cycles) technique. We show that although \( p \)-cycles are better than traditional protection rings in terms of cost-effectiveness (redundancy), the latter surpass the former when the reliability measures are taken into account. We suggest that this fact be considered during network planning.

Keywords—protection rings, \( p \)-cycles, reliability, availability

I. INTRODUCTION

Currently, the optical networks are without doubt perceived as the basis of the Next Generation Internet. It is related to the fact that the optical technology of today, DWDM, is perfectly suitable for carrying large amounts of traffic. The evolution of network concepts developed by standardization bodies, related to ASON [1] as well as GMPLS [2] for the common control plane for optical networks, can serve as a confirmation of such a trend.

However, there are two sides to the optical technology: advantages related to the possibility of meeting the needs of highly demanding clients and, on the other hand, challenges related to the necessity of the network resilience assurance. Both result from the fact that large amounts of data are transported over an optical link. Thus, the guarantee of the efficient and robust recovery methods is also indispensable in the Next Generation Internet.

Since the moment when the classical methods were successfully introduced in SDH/SONET networks, usually built in the ring topology, the researchers have focused on the recovery methods related to mesh networks. There is a common agreement that the Next Generation Internet (NGI) will be based on such networks. They enable efficient routing and resource usage. Carriers try to take advantage of these features and this is the reason why they strive to deploy new recovery methods which are, first of all, fast and cost-effective. The cost-effectiveness is related to the sharing of spare resources that are reserved to meet the recovery needs of traffic transported on more than one working path. If the sharing is taken into account, such working paths are disjoint, and single failures do not usually cause problems. However, we should also pay heed to multiple failures. There are also other reasons to deal with such failures, e.g., maintainability issues [3].

The NGI core network will consist of very long spans built using the optical technology. An optical fiber failure can be caused by many reasons, e.g., fibers can be broken by construction workers or bitten through by rodents. Fiber failures are quite common. Some estimates say that they occur as often as one per year per every 300 km of the span [4]. Failures of other optical devices, e.g., transponders, optical amplifiers or regenerators, optical add-drop multiplexers (OADMs), optical cross-connects (OXCs), are also relatively frequent [5]. If one realizes that the networks which will form the structure of the NGI will be built on the basis of thousands of kilometers of fibers, it will be easier to understand that multiple failures should be taken into account and not overlooked in the recovery planning.

Although we agree that cost-effectiveness should be one of the objectives of the network design, we emphasize the fact that in the case of the recovery planning the first goal must be related to the reliability because this is the main objective of such activities. In this paper we show that a very promising new technique, \( p \)-cycles, often compared to traditional rings and considered as better, can be evaluated as inferior when the most important factor, i.e., the reliability, is taken into account.

Section II presents the concept of traditional protection rings for optical networks. Section III is devoted to \( p \)-cycles built in the context of optical networks. In the subsequent section we derive the formulas describing the operation of protection rings and \( p \)-cycles from the reliability standpoint. Section V is devoted to the comparison of rings and \( p \)-cycles. It is based on the steady-state availability and uses the results derived in Section IV. In the last section we present our conclusions concerning the usage of the studied techniques.

II. PROTECTION RINGS

The idea to base protection techniques on rings is not new. In the mid eighties in the USA the concept of SONET, later adopted as SDH in many other countries, was born. Simultaneously to developing the synchronous optical networks, a lot of effort was devoted to design such networks as resilient to failures. The culmination of it was the series of ANSI and ITU-T recommendations which describe the protection methods based on the ring topology. These are Unidirectional or Bidirectional Self-Healing Rings (there are differences in terminology, for example in the SDH recommendations, the latter are called \( MS-SPR \) rings). These
concepts have been adapted for all-optical networks ([6]-[8]). In the case of protection rings the ‘nodes’ referred to will always be OADMs. We give here only a short overview of protection rings as they are well-known and understood.

A. Unidirectional Path-Switched Ring (UPSR)

In UPSR each pair of nodes is connected by two separate paths. These paths do not share any common nodes or links with the exception of the source and sink nodes. Traffic from the source node is transmitted simultaneously in both directions: clockwise on the working path and counterclockwise on the protecting path. The working path is located on a fiber which is different from the fiber carrying the protection path. In the case of any working path element failure, the sink node starts to receive signals from the protecting path. From the reliability standpoint, UPSR can be described as the dedicated (1+1) protection. The structure of such a ring is shown in Fig. 1.

B. Bidirectional Line-Switched Ring (BLSR)

In BLSR, the nodes are connected by four fibers. There are also 2-fiber BLSRs, but we do not consider them here. Working traffic in a BLSR can be carried on both directions along the ring, usually on the shorter of the two possible paths. The working connection as well as the protecting connection use separate pairs of fibers. The BLSR topology and its behavior during failures are presented in Fig. 2. It is important to note that in the case of a failure the BLSR reacts in two ways. Span switching (Fig. 2c) consists in rerouting traffic from the working fiber to the corresponding protecting fiber, i.e., between the same nodes.
It is possible that only one of the corresponding fibers will fail. Since the working and protecting fibers are not disjoint, this usually concerns the situation where only transponders fail. However, in our analyses we assume that the corresponding working and protecting fibers are statistically independent. In the case of ring switching (Fig. 2d) which is related to a fault of all four fibers between two nodes, the data is rerouted around the ring on the protecting fibers. From the reliability point of view, BLSR represents the shared method.

UPSRs as well as BLSRs can be created on the basis of the whole fibers or optical channels/wavelengths. For the sake of simplicity we will not deal with distinguishing such approaches. Our analysis can be easily adapted to the chosen protection granularity. Usually, the failures of wavelengths and fibers are strongly correlated. Therefore, we talk interchangeably about a failure related to a fiber/link instead of the failure of a wavelength. In the case of p-cycles, it could be more justified to deal with wavelengths. We do not use this distinction for the sake of clarity. Nevertheless, this simplification does not limit the generality of our analysis.

III. PRECONFIGURED PROTECTION CYCLES (P-CYCLES)

This section is mostly based on [9]. p-Cycle is the abbreviation of the technique called preconfigured protection cycle. The idea was introduced in 1998 [10]. Analogously to rings, p-cycles can be treated as protection schemes, because the resources are reserved and allocated before a failure occurs. p-Cycles are very flexible. First, they can be applied in combination with different transmission technologies: from packet-switching (e.g., Internet Protocol), through virtual connection oriented ones (GMPLS) to circuit oriented (DWDM). Secondly, they can be used in multi-layer networks (the most typical scenario: IP-over-DWDM) and applied in many layers simultaneously. Thus, they are a very attractive solution for the NGI. In this paper, we elaborate only on the DWDM-based p-cycles.

This technique is generally independent of the topology of a network in which it is applied. Networks characterized by a high average nodal degree are the ones in which p-cycles show their best effectiveness. Therefore, p-cycles are best suited to mesh topologies.

p-Cycles can be constructed on the basis of add-drop multiplexers (typically of ring topologies) as well as of optical cross-connects (typically of mesh topologies). Thus, in the reliability analysis of p-cycles, ‘node’ refers to OADM as well as to OXC.

p-Cycles can be cost-effectively designed before a failure occurs, when working paths are set up. It does not mean that there are special requirements concerning these working paths. This is one of the most important differences to rings which obviously demand that primary paths be routed in a specified way. This constraint is dropped in the case of the p-cycles-based protection. Working paths can be routed in any way, i.e.,

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**Figure 3.** Data flow in a p-cycle: a) data flow traversing an on-cycle span of 9-node p-cycle (a green line) before failure, b) the p-cycle reaction to an on-cycle span failure, a) data flow traversing a straddling span of 9-node p-cycle before failure, d) the p-cycle reaction to a straddling span failure (one of the two possibilities). Dash/dotted lines indicate the physical routes of protecting paths.
the best one in particular (e.g., provided by shortest path algorithms). After this step, the \( p \)-cycle at the next stage of the design is suited to the chosen working paths. This is possible because a \( p \)-cycle, unlike a ring, is a structure wholly formed up by spare resources. It is the closed path which is set up before a failure occurs, in the way illustrated in Fig. 3a,b where backup capacity allocation for \( p \)-cycle purposes is indicated with a green line. The working resources can also be allocated in the physical link traversed by a \( p \)-cycle. They are protected by the cycle, too. If such a link (called on-cycle span) fails, the \( p \)-cycle behaves like BLSR, when it performs ring switching (cf. Fig. 3b). In this respect the \( p \)-cycle does not present its new features. They are related to the handling of the faults of so-called straddling spans. Such a span is identical with a link which does not belong to a \( p \)-cycle, but two nodes incident to this link form a \( p \)-cycle. The behavior of a \( p \)-cycle in the case of a straddling span failure is shown in Fig. 3d. Let us note that the data can be rerouted in two directions, because the \( p \)-cycle can use its two complementing parts. The traffic which normally is transmitted from node \( A \) to node \( B \) in Fig. 3c can be now routed by two distinct routes, indicated with dashed/dotted lines in Fig. 3d. To use the advantages of \( p \)-cycles the data from the faulty link are divided in two cycle “halves”. Thus, in the context of \( p \)-cycles, for one spare wavelength reserved in a \( p \)-cycle there are up to two working wavelengths allocated in a straddling span. It is paid by a longer route traversed by the restored signal. Spare and working capacity can be considered on the level of all fibers/links or even any level of capacity (e.g., in IP-over-DWDM networks). And similarly as it was assumed in the case of rings, we do not differentiate fiber from links in a reliability analysis.

IV. THE RELIABILITY OF CONNECTIONS PROTECTED BY RINGS AND \( p \)-CYCLES

The methodology of reliability assessment is similar to the one presented, for example, in [11]. Some basic notions related to the availability analysis can be found in [12].

First we derive formulas for the reliability function. It is the most generalized formula. Then, we apply the availability models in the next section, where the numerical examples will be presented. Both types of formulas are universal; they are useful not only in the case of single failures, but also in the case of multiple failures. It will be interesting from the comparisons point of view.

Reliability \( R(t) \) can be defined as the probability that the system operates successfully for a given period of time \((0,t)\) under environmental conditions [13]. We assume that in time \( 0 \) the system is operational.

For each structure we derive two types of reliability:

- all-terminal reliability, and
- two-terminal reliability.

If a network consists of \( N \) nodes, the all-terminal reliability \( R_{\text{all}}(t) \) is defined as the probability that all \( N \) nodes are connected for a given period of time \((0,t)\). Two-terminal reliability \( R_s(t) \) is calculated for the selected source node \( s \) and termination (sink) node \( t \), and equals the probability that these nodes are connected (therefore, it is also called \( s-t \) reliability) for a given period of time \((0,t)\). Nodes are connected, if there is an operational path between them, on which traffic can be transported. Perceived from a user perspective two-terminal reliability can be used as one of QoS indicators.

For simplicity, in all cases we assume that the self-healing operates well, i.e., we do not take into account the probability that backup switching systems fail. Additionally, we deal only with failures of fibers/links. Taking into consideration node failures would also unnecessarily complicate formulas and do not add many new facts to our analysis. Therefore, we assume that node reliability \( r_{\text{node}}(t) = 1 \), and we do not take it into account in the remainder of the paper.

In our analysis we assume that failures of two links (even located between the same nodes) are statistically independent. This is not always the case, but it considerably simplifies the analysis and does not significantly influence the generality of our results.

We use the following notation: \( N \) is the number of nodes in a ring/\( p \)-cycle; \( L \) is the number of straddling spans in a \( p \)-cycle; \( k \) is the distance between \( s-t \) nodes; \( r(t) \) is the reliability function of a fiber/link; \( A \) is the steady-state availability of a fiber/link.

A. UPSR

All-terminal reliability for UPSR is related to the probability that every node can receive/transmit data from/to any other node by using the working fiber or in the case of a failure(s), by using the protecting fiber. All nodes are connected when one of the following statements is true:

- (a) all working fibers are operational (there are no failures on the working path) or all protecting fibers are operational (there are no failures on the protecting path), or
- (b) only one pair of corresponding fibers (working and protection) is faulty, but all other fibers are operational.

Therefore, we can derive the all-terminal reliability formula for UPSR as

\[
R_{\text{all-UPSR}}(N,t) = r^N(t) + r^N(t) - r^N(t) \\
\quad + N \times [1 - r(t)]^2 \times r^{N-1}(t) \times r^{N-1}(t) \\
= 2 r^N(t) + N r^{2N-1}(t) \\
- 2 N r^{2N-1}(t) + (N-1) r^{2N}(t) \quad . \tag{1}
\]

The formula for the two-terminal reliability for UPSR will be dependent on \( k \), the distance between \( s-t \) pair. It is measured

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as the number of spans on the working path between them (cf. Fig. 1). To derive the formula we take advantage of the fact that a two-terminal connection in UPSR is an example of a 1+1 protection and from the reliability point of view forms a parallel-serial structure. Thus, the two-terminal reliability is given by

\[ R_{2,\text{UPSR}}(N,k,t) = 1 - \left[1 - r^k(t)\right] \times \left[1 - r^{N-k}(t)\right] = r^k(t) + r^{N-k}(t) - r^N(t) \]  \hspace{1cm} (2)

B. BLSR

Although we analyze 4-fiber BLSRs, we do not take into account the direction of the fibers in the pair of working fibers. We assume that the failure of the clockwise/counterclockwise working fiber is always related to the failure of the corresponding working fiber, although they are statistically independent of the failures of the protecting pair of fibers. Also, the latter pair is treated as fully correlated from a failure point of view. This is shown in the simplified pictures presenting the operation of BLSR (Fig. 2b-d).

All nodes of BLSR are connected if there are no failures or if failures occur but span or ring switching performs well, i.e., the set of failures do not exclude the successful transport. Such a situation can be disassembled into the following events:

- (a) all pairs of corresponding working-protecting fibers are operational (there are 0 up to \(N\) successful span switchings),
- (b) exactly one pair of corresponding fibers is faulty and all other fibers are operational (there is exactly one ring switching and no span switchings).

Therefore, the all-terminal reliability for BLSR is obtained as

\[ R_{all,\text{BLSR}}(N,t) = \left[\frac{1}{k} \times \left[1 - r(t)\right]^2\right]^N + N \times \left[1 - r(t)\right] \times r^{N-2}(t) \]

\[ = r^N(t) \times \left[2 - r(t)\right] + Nr^{N-2}(t) - 2Nr^{N-1}(t) + Nr^N(t) \]  \hspace{1cm} (3)

Similarly as in the case of UPSR, two-terminal reliability for BLSR will be dependent on the distance between \(s\)-\(t\) pair (cf. Fig. 2a). There is only one difference: it is assumed that the traffic in the normal mode is transmitted on the shortest path. The two-terminal reliability for BLSR is related to the alternative of the following probabilistic events:

- (a) all fibers of the working path are operational,
- (b) exactly one pair of corresponding fibers in the working path is faulty and all other fibers of the working path are operational and all protecting fibers in the protecting path are operational (there is one successful ring switching in the working path), or
- (c) there is at least one successful span switching in the working path (up to \(N\) span switchings), and there are no ring switchings in the working path.

After summing up the probabilities of the above events, we obtain the following formula for the two-terminal reliability for BLSR:

\[ R_{2,\text{BLSR}}(N,k,t) = r^k(t) + k \times \left[1 - r(t)\right] \times r^{N-1}(t) \times r^{N-k}(t) \]

\[ + \sum_{i=1}^{N} \left\{ \left( \begin{array}{c} k \\ i \end{array} \right) \times \left[1 - r(t)\right] \times r^{i-1}(t) \times r^i(t) \right\} \]

\[ = r^k(t) + kr^{N-k}(t) - 2kr^{N-k+1}(t) + kr^{N-1}(t) + kr^{N-k}(t) \]

\[ + r^i(t) \times \left[2 - r(t)\right]^i \]  \hspace{1cm} (4)

During calculation of (4) we take advantage of the fact, that

\[ \sum_{i=1}^{N} \left\{ \left( \begin{array}{c} k \\ i \end{array} \right) \times \left[1 - r(t)\right] \times t^{i-1} \right\} \]

\[ = \sum_{i=1}^{N} \left\{ \left( \begin{array}{c} k \\ i \end{array} \right) \times \left[1 - r(t)\right] \times t^{i-1} \right\} - 1 \]

\[ = [1 - r(t) + 1] - 1 = [2 - r(t)] - 1 \]  \hspace{1cm} (5)

Here and below, for \(p\)-cycles, we take into account the advantageous situation in which a working path for which the formula is derived does not lack shared spare resources, i.e., it is affected by failures before other paths become faulty.

C. \(p\)-Cycles

In a \(p\)-cycle all nodes are connected when one of the following statements is true:

- (a) all working fibers are operational,
- (b) exactly one of the on-cycle fibers is faulty and other working fibers are operational and all \(p\)-cycle fibers (except for the one that is co-located with the faulty one) are operational,
- (c) exactly one of the straddling spans is faulty and other working fibers are operational and all \(p\)-cycle fibers are operational.

We have to focus for a while on the last event. Although in the case of the straddling span only one of the “halves” of the \(p\)-cycle could be used, we demand that in such a situation the whole \(p\)-cycle is operational. This is related to the fact that we would like to draw all possible advantages from using the \(p\)-cycle. During the calculation of the all-terminal reliability for a \(p\)-cycle we assume that it is used in a maximally efficient way.

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That means that we assume that there are two protected channels on the straddling span and, after a failure, one of them will be rerouted on one “half” (side) and the second on the other. Additionally, these two channels on the straddling span are 100% statistically dependent, i.e., they are operational/faulty at the same time.

The formula for the all-terminal reliability of a p-cycle is also dependent as follows on the number of straddling spans L:

$$R_{\text{all},p}(N,L,t) = \frac{r_{p+1} - L}{(N-1)} + N \left[ 1 - r(t) \right] \times r_{p+1} \times r_{p-1}(t)$$

$$= r_{p+1} - kr_{p+1} + r_{p+1} \times r_{p-1}(t)$$

where $L \in \left[ 0, 1, \ldots, \frac{N-1}{2}, \ldots, N \right]$. 

Similarly as in the case of the two-terminal reliability for UPSR or BLSR, the two-terminal reliability for a p-cycle will be dependent on the distance parameter $k$. Here, $k$ is the number of on-cycle spans on which the signal is present on the p-cycle or the minimum number of such spans between the nodes adjacent to the straddling span on which the signal is present. Such a parameter can be identified with the number of spans between the source and sink nodes in UPSR or BLSR. We do not take into consideration the situation where the signal is present simultaneously on on-cycle and straddling spans, or on more than one straddling span. For example, in Fig. 3a we have $k = 2$. The two-terminal reliability should be calculated in the case of p-cycles separately for an on-cycle span and a straddling span.

Two nodes, characterized by a working path traversing $k$ on-cycle spans, are connected when one of the following statements is true:

- (a) all $k$ on-cycle spans between the nodes are operational,
- (b) exactly one on-cycle span between the nodes is faulty and other $k-1$ on-cycle spans are operational as well as $N-1$ spans of the p-cycle.

Therefore, the two-terminal reliability will be

$$R_{\text{2},p,t}(N,k,t) = r(t)^k \times \left[ 1 - r(t) \right] \times r_{p+1}(t)$$

$$= r(t)^k - kr_{p+1} + r_{p+1} \times r_{p-1}(t)$$

(7)

- On the other hand, two nodes are connected by a straddling span in the case of the following events:
- the straddling span is operational, or
- all $p$-cycle spans on one side of the $p$-cycle are operational, or
- all $p$-cycle spans on the other side of the $p$-cycle are operational.

This is the case of 2:1 protection. We can use the parallel-serial reliability structure which is shown in Fig. 4. Now we take the most advantageous case where there is only one channel on the straddling span and it can be rerouted on one of the operational paths formed by the p-cycle. The two-terminal reliability calculated on such a basis is equal to

$$R_{\text{2},p,t}(N,k,t) = 1 - \left[ 1 - r(t) \right] \times \left[ 1 - r(t) \right] \times \left[ 1 - r\left( t \right) \right]$$

$$= r(t) + r(t) - r(t)^2 + r(t)^3$$

(8)

V. RINGS AND P-CYCLES: A COMPARISON

The advocates of p-cycles eagerly stress their prevalence over protection rings. For example, [14] enumerates the advantages from the standpoint of: modularity, protection yield, protection flexibility, routing and provisioning of working paths, network redundancy and average length of protection paths. We agree with all these points. However, we would like to pay heed to the one feature that is not mentioned in it. In the previous section we derived formulas which describe the reliability functions for UPSR, BLSR and p-cycles. Now, we would like to present numerical examples which prove that, from the reliability point of view, the superiority of p-cycles can be contested.

We apply the availability models to the reliability formulas derived in the previous section. We use steady-state availability (A). The exact definition of it is given in [15]. For our purposes it could be understood as the probability that an item (link, network) is up (in the operational state) at any point in time [13]. Therefore, in contrast to the reliability, it is a number. The operation consists in the substitution of the $r(t)$ function by $A$ in all formulas.

At first, we present the comparison of all-terminal availabilities. It can be seen in Fig. 5 that p-cycles can be described by numbers inferior to those characteristic for protection rings. It is apparent that BLSR is related to the large
resilience, while UPSR and $p$-cycle is much worse. Additionally, $p$-cycle is far less reliable than UPSR. Obviously, the availability decreases with the growing number of nodes and straddling spans. We consider the theoretical case, so we do not take into account the standard restriction on 16 nodes for BLSR and UPSR rings.

In Fig. 5 we can see that although the large number of
straddling spans is attractive, each next straddling span considerably decreases the all-terminal availability for a p-cycle. Fig. 6 presents the all-terminal availability of p-cycles consisting of 20 nodes. The availability decreases fast with the growing number of straddling spans.

The presented values are related to a quite large network. But one should take into account that NGI networks will consist of such a large number of nodes, e.g., inter-continental backbone networks of global operators. We can see that even for representative values of fiber availability \( A = 99.5\% \), the all-terminal reliability decreases very fast and even for small numbers of straddling spans it reaches unsatisfactory levels. On the other hand, the all-terminal availability can be recognized as satisfactory in a quite large range of \( L \)'s in the case of relatively large link availability values \( A = 99.9\% \). A three 9's level of link availability means that the fiber is approximately 100 km long. Such a short length of a span is obviously possible, but rather in metropolitan networks, not in wide area networks. It would suggest that p-cycles could be a good solution for MANs. This can also be a chance for introducing this new technique in the NGI. On the other hand, it would be neither necessary nor possible to lay straddling spans in MANs.

The comparison of the two-terminal reliabilities is also interesting. The end-to-end perspective seems to be better for p-cycles than the all-terminal reliability. The example is shown in Fig. 7.

The picture shows that the two-terminal availability of an on-cycle span is worse than the analogous availability in both rings. This is related to the fact that the protecting path in a p-cycle is longer than its ring equivalents. The most surprising can be the fact that it is also true in the case of the p-cycle to UPSR relation. On the other hand, the two-terminal availability of p-cycles is better than two-terminal availability of rings (it could be not visible in the picture, but it is the case also for the p-cycle to BLSR relationship). The reason is that from the straddling span standpoint, p-cycle protection constitutes a 2:1 connection. This proves the fact that all p-cycle advantages are related to straddling spans.

The results suggest that the prevalence of p-cycles over traditional protection rings can be contested. The reason for this lies in the fact that both types of techniques are quite rigid. We can see this feature especially in the case of the BLSR and p-cycles comparison. Although both schemes enable sharing, their behavior after a failure is fully determined and does not leave any room for flexibility needed in the case of a secondary failure. And then the fact that is the greatest advantage of p-cycles (the existence of straddling spans) appears to be also their greatest disadvantage: the secondary failure is more likely to occur, since the more spans, the greater probability of faults. As p-cycles are designed to be resilient to single failures only, the secondary failure must incur a fault which cannot be recovered.

VI. CONCLUSION

We showed the importance of reliability assessment for the evaluation and comparison of different recovery methods which are investigated as a potential technique for the NGI. The derivation of the formulas describing the all- and 2-terminal reliability and the numerical examples prove that the dominance of p-cycles over protection rings is doubtful. The reader should note that we omit node reliability. Considering of node reliability would make the reliability functions for p-cycles far more inferior because this technique is not well suited for treatment of node failures.

We propose to use such an analysis at the stage of preparation of network recovery procedures for the NGI. The speed of the method and cost-effectiveness related to the redundancy can be insufficient to make a satisfactory choice. p-Cycles can be very attractive, but they are satisfactorily reliable only for quite large values of fiber availability. This would restrict their usage to metropolitan area networks.

REFERENCES