On the Protection of Multicast Trees in All Optical Networks Using the NEPC Strategy

Miklós Molnár

▶ To cite this version:

Miklós Molnár. On the Protection of Multicast Trees in All Optical Networks Using the NEPC Strategy. RR-11022, 2011. lirmm-00611957

HAL Id: lirmm-00611957
https://hal-lirmm.ccsd.cnrs.fr/lirmm-00611957

Submitted on 27 Jul 2011

On the Protection of Multicast Trees in All Optical Networks Using the NEPC Strategy

Miklós MOLNÁR

University Montpellier 2, IUT, Dep. of Comp. Sci.,
Laboratory LIRMM - UMR 5506- CC 477,
161, rue Ada
34095 Montpellier Cedex 5, France
molnar@lirmm.fr

Abstract. Due to the huge volume of the carried data in all optical networks, the ability of these networks to cope with failures becomes crucial. One of the proposed mechanism is the protection of the routes (lightpaths and light trees) with the help of precomputed ans reserved backup routes permitting to rapidly change the routes in the case of failures. The protection with p-cycles is an efficient method, which was originally proposed to protect on-cycle and straddling links. Recently the cyclic protection was extended to protect nodes in lightpaths and in light trees. As light trees can contain some branching nodes where the incoming light is spitted to several outgoing sub trees, the protection of these kind of trees is more delicate. In opaque networks where the switches may be virtual sources, efficient cycle-based protection schemes can be computed since each node can be the source of newly inserted light branches on an arbitrary precomputed cycle. Contrarily, with the apparition of optical switches and all optical solutions in core networks, the protection scheme should correspond to stringent optical constraints. Namely, the branching nodes of a protection scheme must correspond to available splitters. That is, the protection of multicast trees is limited in all optical domains. Our paper aims with the formulation of the potential protection possibilities and give the conditions to apply NEPC based protection.

Keywords: all optical network, multicasting, fault-tolerant routing, p-cycle, optical constraint

1   Introduction

On the one hand, due to they huge capacity and robustness, all optical networks are becoming increasingly important in core networks. On the other hand, in recent multimedia applications, the communications should not be interrupted for a long time by a failure of a link or a switch. A failure can implicate important packet losses. Since the duplication of

communications using independent routes is expensive, shared cold protection mechanism is often proposed as solution. With route restoration, when a failure is detected, a new route to the destination is requested, computed and configured in a reactive manner [12]. This solution may correspond to a high recovery delay. In the case of precomputed protections, the routers and switches reroute the communications to the pre-planned backup routes in case of a failure [11]. So, this solution is faster. To successfully redirect the affected traffic, sufficient capacity should be allocated to precomputed backup routes. Protection can be dedicated to protect some privileged targets (links and/or nodes) and can correspond to a shared protection scheme, where a same backup possibility may protect against different failures. Often, a given backup resource may protect several primary target but only one target at a time. In [13]the authors state that shared protection provides significant savings over dedicated protection but shared protection is more susceptible to multiple link failures than dedicated protection.

Often, to characterize the quality of a protection, two measures of a solution are considered: the recovery delay and the number of failures managed [4]. Moreover, the efficiency of a protection scheme can be given by the ratio of the protected primary communication capacity and the needed backup capacity.

It is therefore critical to reduce the recovery delay as far as possible. A good candidate for this reduction is a protection scheme based on small cycles permitting fast local recoveries in the case of failures. Trivially, a single cycle can not protect against multiple failures but a set of cycles can.

Grover and Stamatelakis proposed in [7] a protection methods based on pre-configured protection cycles (or p-cycles) for WDM networks. The p-cycles offer the advantages of both ring and mesh protection schemes. Namely, restoration time can be fast as in ring protection, and protection efficiency can be high as in mesh-protection schemes. p-cycles may protect not only on-cycle links but also straddling links of the cycle. Moreover, cycles can be applied to perform an efficient shared protection. To protect a traffic pattern, a set of p-cycles should be computed. Since the optimal p-cycle set design is NP-hard [7], several heuristic design algorithms were proposed [6] [3].

Often the design of pre-configured protection cycle can be made at the same time that the primary route design and the optimization can concern both the primary and the backup route design. In these cases the optimizations are inseparable and we talk about joint optimization of the

(protected) routing scheme. Consequently if the optimization of the protection scheme follows the primary route computation, the optimization is a non-joint optimization.

Link failures are more frequent, but generally node failures impact several communications traversing the failed node. A node failure can be equivalent to several link failures. Dedicated protection schemes which offer separated solutions for link and node failure recovery are expensive. Accordingly, solutions proposing a combined link and node failure recovery are more interesting. A good protection scheme offers solutions against both link and node failures. The extension of p-cycle based schemes for node failure protection is one of the ideas providing a combined protection. If an on-cycle node is failed, then the cycle may trivially be used to protect the communications traversing it. The p-cycle concept was extended to path segment protection against possible node failures in [14] where a capacity optimization model was also developed. The authors found that using p-cycles only a small additional spare capacity is needed to achieve a good node-failure protection. Node-encircling p-cycles (NEPCs) may protect node failures as it is explained in a first model of the paper [2]. A single set of NEPCs was proposed for combined node and span protection. NEPCs can be shared by several nodes, and each node may use as many different NEPCs as needed for a capacity-efficient usage of the backup capacities. A different, failure-independent path-protecting p-cycle scheme (FIPP) was proposed in [9], that extends the p-cycle concept into a path-oriented protection. In this manner, FIPP p-cycles become similar in capacity efficiency to shared-backup path protection (SBPP, cf. [8]), supporting failure-independent end-node activation and control against either span or node failure with fully pre-connected protection paths.

Our study focuses on the applicability of the NEPC strategy to protect multicast light trees.

2   Protection of Multicast Trees

Multicast protection schemes are classified in [25] into five major schemes: tree-based, ring-based, path-based and segment-based protections.

A trivial solution for the protection of a multicast tree (originally in ATM networks) has been proposed in [17] based on the extraction of all the paths from the root to each destination in the multicast tree and then protect each paths with a unicast protection scheme. This solution

is easy to realize in optical networks but is very expensive since the shared protection of the common part of the paths is not resolved.

A protection scheme of a multicast session against any single link failure in an optical network has been proposed in [16]. A path-pair (disjoint primary and backup paths) is computed to each destination by the optimal path-pair-based shared disjoint paths (OPP-SDP) algorithm. The paths can share edges with already-existing path pairs and also with other edges on the primary tree. An improved version called "cross-sharing" has been proposed in [15] which improves the backup sharing. It allows to share available backup capacities of multiple multicast sessions. Portions of backup paths of a given multicast session not only self-shares with its primary tree but also cross-shares with the portions of backup tree of other sessions.

A different solution for tree protection is to complete the primary tree by links producing redundancies and cycles and protecting all links and nodes in the primary tree. In [5], a dual-tree scheme for multicast fault-tolerant is proposed. In this protection technique, the primary tree leafs are interconnected without the use of any link or inner node of the primary tree. The obtained redundant scheme contains a spanning tree which can be used even if there are failures.

The computation of edge-disjoint spanning trees for primary and backup routes is also a natural idea [18]. In this case, the backup spanning tree remains unaffected even if the primary tree is failed. The topological constraint for this protection scheme is very hard and necessitates the four-connectedness of the topological graph. Moreover, the edge-disjoint approach does not guarantee vertex-disjoint trees.

ITo facilitate the redundant multicast routing the authors in [10] propose to design two directed arc-disjoint trees (a "multitree"). In this scheme, if any vertex or edge in the graph leaves, each destination vertex remains to be connected to the source by at least one of the directed trees. Despite the advantages and the simplicity of this proposition, there are some disadvantages: the backup capacity is quasi-equivalent with the primary capacity and the redirection procedure may be complicated and may go back to the source.

Often, to formulate protection propositions for optical multicasting, it is supposed that *every switch is of full wavelength conversion capability and optical multicasting capability* (cf. the condition in [20]). These conditions are always true in opaque optical networks where every node may be a virtual source. It can choose the wavelength arbitrary to continue the multicast forwarding in every outgoing fiber. These conditions are

not true in all optical networks. We discuss the specificities of all optical networks in Section 4.

As it is detailed in the next section, p-cycles can also be used with success for multicast tree protection.

3   Cycle Based Link/Node Protection of Optical Multicast Trees

The multicast tree protection by cycles is based on the fact that if a link or a node in the tree fails, the neighbor nodes of the failed element may inform the network control plan and this latter can initiate to switch to backup pre-configured cycles. The procedure must reconnect the disconnected parts of the failed trees by forming a new multicast trees (or an equivalent multicast route, cf. later). The most significant references on cycle based solutions are presented in the following.

F. Zhang and W. D. Zhong proposed the application of p-cycles to dynamic provisioning for multicast sessions in WDM networks in [19]. The design of p-cycle based protection for static survivable multicast sessions was discussed in [25] where several joint and non-joint optimizations and heuristic algorithms are compared. In these works, only link failures were considered. In [25] and [23] Integer Linear Programming (ILP) based methods and ILP based heuristics were formulated for optimal and quasi-optimal p-cycle protection schemes respectively and both in joint optimization and non-joint optimization cases.

The node encircling p-cycle technique may be applied with success even if the node is a branching node of a multicast light tree. The paper [23] proposed a p-cycle based solution for combined node and link failure recovery which can be applied to protect light trees. Further node and link failure protection schemes for multicast traffic protection using the p-cycle concept were proposed and analyzed in [21].

An efficient heuristic algorithm for p-cycle based multicast tree protection has been proposed in [20]. In this proposed version, p-cycles protect light trees on an end-to-end basis, instead of protecting each link and node. In the case of a link failure, trees which are arc-disjoint with the cycle, having the source and the destination nodes on the cycle can be protected. The solution permits the recovery against intermediate node failures. The authors also discuss the conditions how the affected trees can share the protection cycles. Since the end-to-end protection of large trees needs large p-cycles, and it may be difficult to find this kind of p-cycles,

the paper propose a tree partition algorithm to solve the protection of sub trees instead of the whole tree.

In the presented p-cycle based protection schemes it is always assumed that every node is of full wavelength conversion capability and optical multicasting capability. Moreover the light trees are directed and the cycles should complete the trees in the case of a failure by directed paths. The most sensible and complicated case corresponds to the failure of a branching node of a light tree. The basic idea of the propositions based on node encircling can be resumed as follows (such a situation is shown in Figure 1). The cycle P encircles the node b which is a branching node in the directed tree T: there is an ancestor node of b in the tree which is also on the cycle (it is the node a) and all of the sub trees of b are rooted by an on-cycle node (the nodes c, d and e in our example). When a failure of b is occurred, a new connected light tree can be obtained using the recovery capacity of the cycle P as it is indicated in the figure (an arbitrary directed path on the cycle spanning the successor nodes of b is presented in the example). Notice that the network is an opaque network and the nodes c, d and e have multicasting capability and can be virtual sources of the corresponding sub trees.
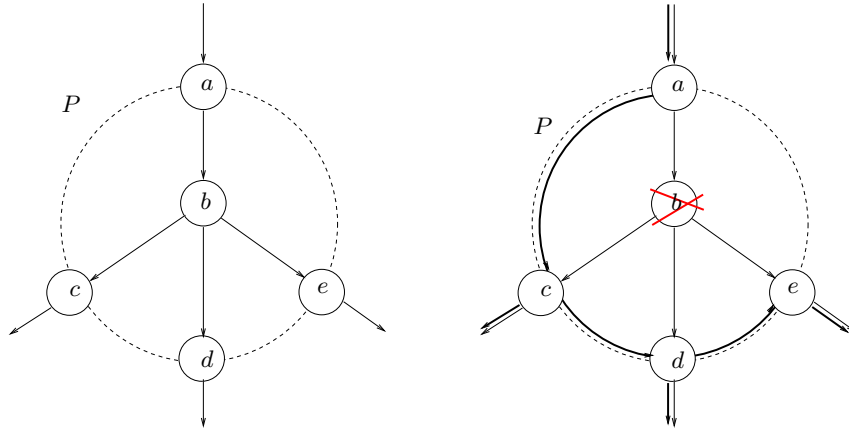
Fig. 1. A cycle P may protect against the failure of a branching node b in a multicast tree in an opaque optical network

Originally, the node encircling p-cycle (NEPC) concepts was proposed in [2]. The cycle presented in Figure 1 is considered as a *simple* NEPC. The authors state if the network graph is at least two-connected,

it is always possible to draw at least one logically encircling *non-simple* cycle which can protect a node failure. Such a non-simple cycle $P = (a, c, d, e, d, f, a)$ is presented in Figure 2. This kind of non-simple NEPC was proposed for node protection in light-paths, but the schema can be adapted for light trees as it is illustrated by the second part of the figure. This figure shows the use of a directed non-simple walk (a, f, d, e, d) belonging to the non-simple cycle to establish the protection against the failure of node b. Even if the same wavelength is used in the multicast tree and in the backup multicast route, this wavelength can cross a switch from different incoming ports to different outgoing ports, and the illustrated non-trivial multicast route can be established after the recovery. The finally obtained backup structure is not a light tree but a light hierarchy which has been proposed in [26].
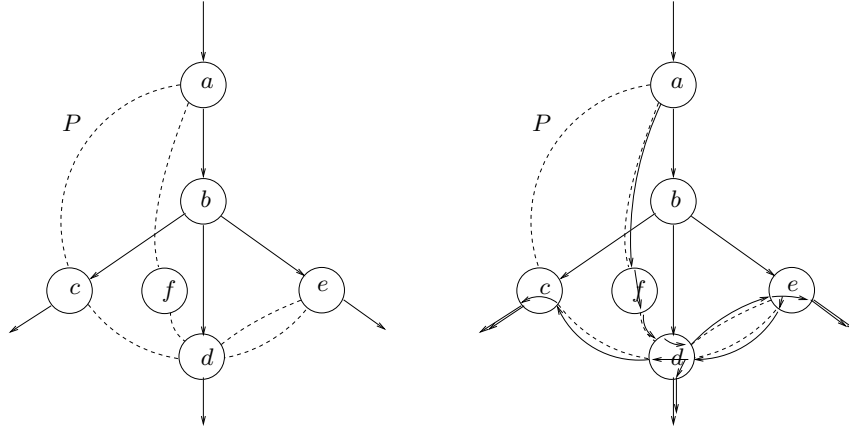

Fig. 2. A non-simple NEPC which may protect against the failure of a branching node b

Trivially, in an opaque network a p-cycle may recover the failure of a branching node, even if the failed node is on the cycle. The condition of the recovery is that all sub trees of the failed node must contain a common node (successor of the protected branching node) on the cycle. Such a situation is illustrated by Figure 3 (the cycle P in dotted line passes through the node b).

Property 1. A cycle is an NEPC (simple or not) and can be used to recover the failure of the encircled node b iff all the neighbor nodes of b are in the cycle.
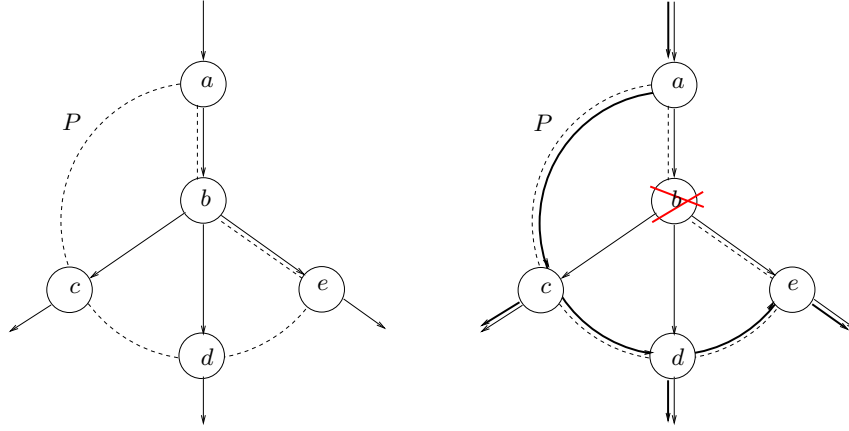
Fig. 3. In an opaque optical network, cycle P may protect against the failure of an on-cycle branching node

Notice that the segments (a, b), (c, b), (d, b), (e, b), ... can contain internal nodes which are not destinations nor branching nodes. To simplify, we suppose that they are simple links. To obtain more large protected parts, a p-cycle can offer the protection against the failure of nodes and links of an encircled sub tree as it is indicated in Figure 4 (in this case, the cycle is not an NEPC encircling only one node). Notice that the encircled sub tree must be free of destinations. If there is a destination in the sub tree, the recovery based on the cycle and regarding the direction of the links in the sub tree can not assume the connection to this destination node. If the widest, the cycle based protection can be applied from the source node and can be concerned the destinations on the cycle as it is the case of the failure independent path-protecting (FIPP) p-cycle approaches applied for multicast trees [21]. In all cases, the encircled sub tree can not contain any destination, only the on-cycle destinations and the destinations that are outside the cycle can simply be protected.

Obviously, more the protected part and the cycle are wide, more the reconfiguration is complicated and slow. Moreover, only the intermediate node failures can be recovered by the cycle and source and destination node failures cannot be restored by any protection algorithm. The source node protection necessitates the duplication of the source as it is explained in [22].

For the previously presented cycle-based protections, opaque networks with multicast capable nodes were supposed. In the following, we analyze
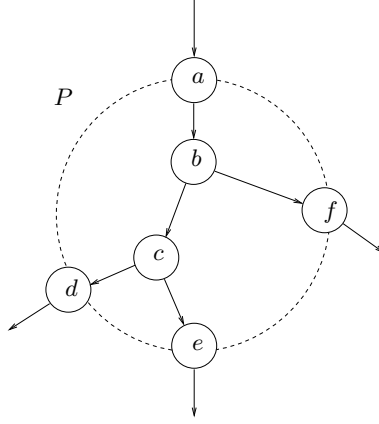
Fig. 4. A cycle P may protect against the failure of any link and node of a sub tree limited by it

the light tree protection possibilities by NEPCs in all optical networks where the optical switches do not obligatory contain splitters.

4   Protection of Branching Nodes of Light Trees under Optical Constraints

In transparent all optical networks, where the nodes are optical switches and the O/E/O conversion in these switches is not desirable, the multicast routing must satisfy additional optical constraints.

– All of the optical switches can not split the incoming light. To perform the multicast routing with a light tree, the branching nodes of the tree must coincide with switches having special light splitters.
– In addition to the uniqueness of the wavelength in the fibers, the same wavelength should be used along the light-paths and light trees. The wavelength can only be changed if there is a wavelength converter in the traversed optical switch. Since our analyzed problem focuses on the sparse splitting constraints for the multicast routing, without loss of generality, we suppose that there are no converters in the network (in the recent study, the conflicts on the wavelength assignment are not analyzed).

Here, we focus on the first, strong constraint corresponding to the splitting capacity of the optical switches. In all optical networks, a node

capable to split the incoming light is called as a Multicast Capable (MC) node, otherwise it is a Multicast Incapable (MI) node [24]. One can suppose that any node (also an MI node) at least has the Tap and Continue ability to tap into the incoming signal for local usage and forward it to only one output [1]. So, any node can be an intermediate destination on a light tree but only the MC nodes can be branching nodes.

Several propositions have been formulated to compute light trees corresponding to these constraints (cf. Reroute-to-Source, Reroute-to-Any, Member-First and Member-Only algorithms in [24]). Typically, if there is not a single light tree satisfying the constraints, a set of trees (a "light-forest") is computed corresponding to them.

As a result of the constraints, not only the primary light trees but also the backup routes obtained after the recovery must satisfy the mentioned conditions. That is, **after the recovery, the eventual branching nodes of the new light tree must correspond to splitters** (to simplify, at a first time, we suppose that the new optical route after the recovery also corresponds to a light tree).

Unfortunately, the splitters may be sparse in an all optical network. In some cases, depending on the network topology, on the availability of the splitters and on the location of the primary light trees, some of the latter can not be protected by the NEPC technique as it is illustrated by Figure 5. In the figures, the MI nodes are represented by squares and the MC nodes are circles. Since the nodes a, c and e are MI nodes, a new optical multicast route covering all of the sub trees of the node b and respecting the constraints on the splitters can not be built when the node b is failed.

Figure 6 presents two different repartitions of the multicast capable nodes in the same network and for the same light tree. In these new situations, the protection with the help of the cycle P against the failure of node b is possible due to the connected MC nodes. Our principal question is the following: *When is it possible the protection of a branching node of a light tree using the capacity of an node encircling p-cycle?* The following proposition gives a necessary and sufficient condition for this protection. Remember, there is no wavelength conversion in the network and the same wavelength should be used after the recovery.

Let $G = (V, E)$ an undirected graph representing the all optical network topology with two type of nodes. Let $T = (W, F)$ be a light tree and b a branching node in the tree. Let P an NEPC encircling b in the topology graph. To simplify we note also by P the set of nodes on the cycle P. Let $S = W \cup P \setminus \{b\}$ the set of nodes in the intersection of the tree
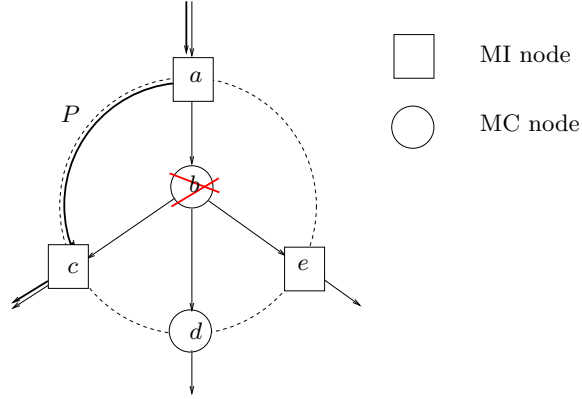
Fig. 5. A configuration of MC and MI type nodes on the cycle P which does not permit the protection against the failure of the branching node b of a multicast tree
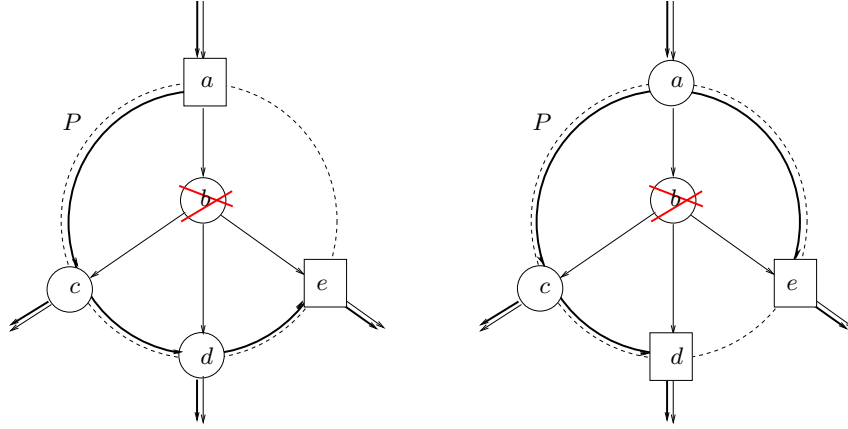
Fig. 6. A cycle P which may protect against the failure of a branching node b in a multicast tree applied in an all optical network

and the cycle except b (as P is an NEPC, S corresponds to the neighbor nodes of b in the tree T).

Notice that the p-cycle may contain several nodes which are not in S. These nodes are only relay nodes in the case of a failure recovery and so they are not relevant for us. Our analysis focuses on the nodes in S.

At first, we give the condition to protect a branching node with a simple NEPC against a failure.

Proposition 1. *A simple NEPC P can protect against the failure of the node b, iff it contains a path PP covering the node set S such that PP does not contains any internal node of type MI belonging to S.*

Proof. Let us suppose that to protect the tree T against the failure of b, a sub-path PP of the cycle P is used after the recovery. In the new optical multicast route (in the new light tree), trivially, the extremities of the path PP have a degree 2 (and so these nodes can be MI or MC nodes) but the internal nodes belonging to S should be branching nodes having one or more sub trees which should be connected to the source).

The condition is necessary. Let us suppose that all paths in P and covering the node set S contain an MI type internal node. Without loss of generality, let P' be such a path and let $v \in S$ the MI type internal node in this path. v separates the nodes of S into two non empty node sets and the path P' into two sub paths. To obtain the connectivity of the two sub paths and also the sub trees rooted in v, v should have a degree 3 or more after the recovery, but v is of MI.

The condition is sufficient. If there is a path PP such that each internal node of PP belonging to S is an MC node, then these nodes can be the new branching nodes of the backup multicast structure. ∎

A non-simple NEPC can extend the protection against a branching node failure of a multicast tree. The difference between simple and non-simple cycles is that non-simple cycles MAY contain several times a same node (a same node can have several occurrences in the cycle). So, the connected subsets of the non-simple cycle are not obligatory paths but may be walks returning several times at a same node. To satisfy the constraints on the availability of splitters, all the node occurrences in the walks should be considered. Figure 7 illustrates two cases, where non-simple NEPC can be used for the protection. In the first example, the non-simple NEPC $P = (a, c, d, e, d, f, a)$ can protect the branching node b (all of the neighbor nodes of b are on this non-simple cycle). In this cycle, two fibers between the nodes d and e are reserved. The nodes a and d are MI nodes. There is no simple path in the cycle satisfying the previous condition (cf. Proposition 1). The figure indicate how the *walk* (a, c, d, e, d) in this cycle can be used to create a backup light hierarchy to recover the failure. As it was shown in the simple case, the extremities of the walk (the nodes a and d) have a degree 2. The particularity of this protection is that the node d is present twice in the walk. Beyond the occurrence corresponding to an extremity of the applied walk, the

12

other occurrence of this node is a simple relay node in the obtained light
hierarchy. The degree 2 of each occurrence corresponds to the fact that it
is an MI node. After the failure recovery, the optical switch d is traversed
twice: at first from c to e and secondly from e to its single existing sub
tree. Of course, as d is an MI node, it can have only one sub tree in the
primary tree. Finally, the degree of each node occurrence corresponds to
the type of the given node (MC or MI).

The second example in the figure proposes an other non-simple NEPC
$P = (a, c, d, f, d, e, d, a)$ using two fibers between the nodes d and e and
also between d and f. To recover the failure of the node b in the indicated
tree (b has four successors in the tree: c, d, e and f), for instance, the
walk (a, c, d, f, d, e, d) can be proposed. The walk returns three times to
the node d and each occurrence of d in the resulted light hierarchy has a
degree 2. These returns using the walk PP are also illustrated in Figure 8.
The generalization of the results is summarized by the following.
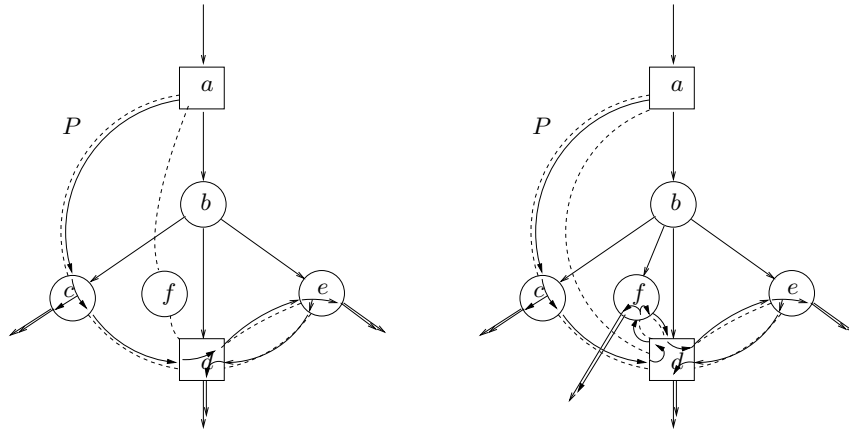
Fig. 7. Non-simple NEPCs permit the protection against the failure of the branching
node b using walks on the NEPC

Proposition 2. *A non-simple NEPC P can protect against the failure
of the encircled branching node b, if it contains a walk PP covering the
neighbor node set S of b such that the internal MI nodes belonging to S
in PP have also an extremity occurrence of PP.*

*In other world: an MI type node can be repeated in the walk PP several
times, if it also has an extremity occurrence in the walk.*
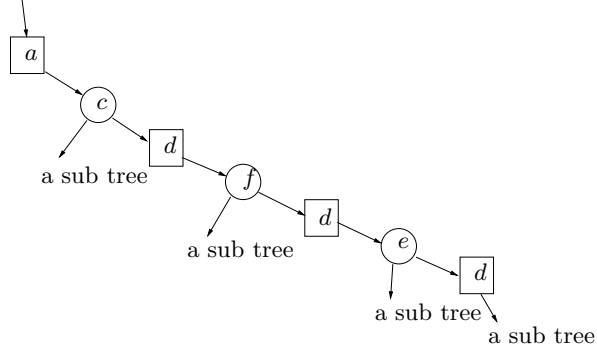
Fig. 8. The detailed walk of the second example

Proof. Let us suppose that to protect the tree T against the failure of b, a walk PP in the non-simple cycle P is applied. Remember that in a walk, a node may appear several times (several occurrences of the node may belong to the walk).

In the new optical multicast route (in the new obtained light hierarchy), trivially, the extremities of the walk PP have a degree 2. The internal nodes of PP belonging to S are either branching MC nodes having one or more sub trees or they are simple relay nodes.

Let $s_i nS$ be an internal relay node, and let T_s its sub tree in the original multicast tree. Let us suppose that s has a relay node occurrence in a path PP. There is two cases:

1. This node s has an occurrence in the walk located at the extremity of the walk. This extremity node occurrence can connect the sub tree T_s to the new multicast route.
2. There is no extremity node occurrence corresponding to s. In this case, the sub tree T_s can not be connected to the new multicast route.

The condition is necessary (cf. 2).

The condition is sufficient. If it is true, all of the sub trees belonging to the nodes in S can be connected to the new multicast route. ∎

Trivially, as a walk has two extremities, only occurrences of these two nodes (if they are MI nodes) can be repeated in the walk used to recover the node failure.

14

5 A Particular Protection Scheme Using Non-Simple Cycles

Non-simple cycles extend the protection possibilities of branching nodes in all optical light trees. In the previously presented cycle-based protection schemes, the cycle (simple or not) is used to the failure recovery in the following manner. *If a node failure occurs, then a sequence of some consecutive nodes in the cycle (i.e. a walk) is used to re-connect the sub trees of the failed optical multicast tree.* Let $P = (x_1, x_2, x_3, \ldots, x_n, x_1)$ a cycle (represented by a circular list of nodes) with n node occurrences (if the cycle is a non-simple cycle, then several occurrences correspond to a same node of the topology graph). The walk used for the protection can be an arbitrary sequence of these node occurrences of the circular list satisfying the previously mentioned conditions.

Eventual returns to some nodes in the cycle permit a different and more flexible (but more complicated) protection of the encircled branching node. In the following, we present a special case based on a particular non-simple cycle. This example also illustrates the protection capabilities of the non-simple cycles.

A particular protection scheme can be proposed when a non-simple NEPC is composed using two fibers (one in both directions) between the connected node pairs in the cycle. Figure 9 shows such an NEPC and its proposed utilization for the failure recovery. There are multiple MI nodes in the cycle, but MC and MI type nodes alternate which permit the protection using the presented NEPC in a particular manner.

In the following proposition, we suppose that the links belonging to a p-cycle can be used arbitrarily for the protection. That is, an arbitrary connected subset of the links (and not only a path or a walk) can serve the protection.

Proposition 3. *Let a non-simple NEPC P be systematically composed from two fibers between the concerned (neighbor) nodes. It can protect against the failure of the encircled node b if it contains a path PP covering the node set S of neighbors such that the path PP does not contain a sequence of three successive internal MI nodes belonging to S.*

Proof. Each node s in S has at least one sub tree T_s rooted in s which must be re-connected to the source after the failure recovery. Trivially, if s is an MI node, it has only one sub tree in the original multicast tree. Moreover, each node occurrence of an MI node can have a degree 2 in the recovery structure. Contrarily, the MC nodes can be branching nodes after the recovery.
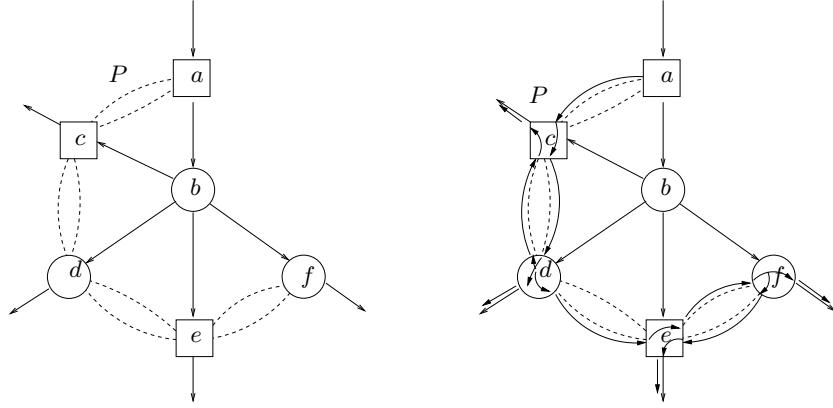
Fig. 9. A particular non-simple NEPC and its usage for the protection against the failure of the branching node b using a particular walk on the NEPC

The capacities in the mentioned NEPC can be allocated to the failure recovery as follows. From the source, the visited MC nodes belonging to S are branching nodes. Let us suppose that an internal MI type node s is a relay node in the NEPC. Remember that the unique sub tree T_s can not be connected to the backup structure by this node occurrence of s. To this, the backup structure must return to s from an other visited node. If PP contains three successive internal MI nodes belonging to S, and there is no MC node between them, the return to the middle MI node in S is not possible using the cycle. Let s_1, s_2 and s_3 the three successive MI nodes in the cycle (cf. Figure 10). In the best case, the sub trees of s_1 and s_3 are connected to the recovery structure using incoming links (l_{01} and l_{43}) as it is illustrated. Moreover, a path from s_1 to s_3 must be used to connect the two parts of the multicast routes. Since s_1, s_2 and s_3 are MI nodes, the middle node s_2 can be a relay node in this path but can not be branching node. Its sub tree can not be connected to the multicast route using the in-cycle links.

If there is at least one MC node (named t) either from s_i to the next MI node in S or before s_i, then this node t becomes a branching node and the not yet used path from t to s_i can connect the sub tree of s_i to the backup structure. ∎

Figure 11 illustrates two cycles: one with a feasible and another with a not feasible sequence of nodes.

16
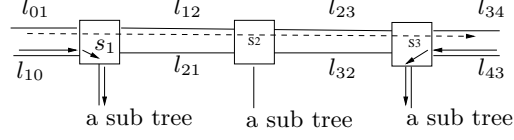
Fig. 10. The sub tree of the middle MI node can not be connected to the recovery structure

The particularity of this protection is that it uses not only a path or a walk in the cycle but also other related links which are connected to the basic path. So, the configuration of the protection concernes not only the configuration of the nodes following the walk or the path scheme but it is completed with some additional configurations. The obtained backup structure is a light hierarchy using the capacities of different in-cycle links.
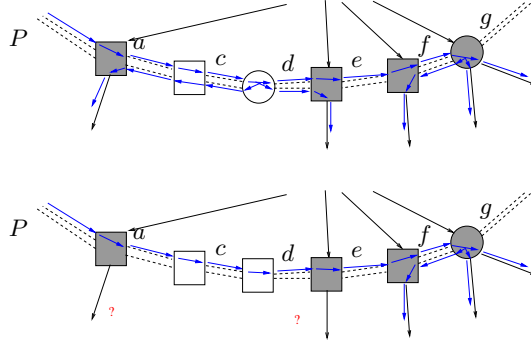
Fig. 11. A feasible and a not feasible sequence of nodes in an NEPC using a backup hierarchy on the cycle

6 Perspectives

In this study, we presented the conditions how NEPC can be used to protect light trees against branching node failures in all optical WDM networks. The most important contribution of this work is simple: the backup multicast route must correspond to the well known optical constraints. We analyzed the constraint imposed by spare splitting capacities in the network. The branching nodes of the backup route must be MC nodes.

We also presented how non simple NEPCs can be applied to the failure recovery. Often, this application leaves to the formulation of backup light hierarchies. They extend the protection possibilities but the configuration of these hierarchies is more complicated.

The analysis of the protection of multicast routes in all optical networks needs intensive future works. In real all optical networks, all of the feasible light trees can not be protected against branching node failures. A deep analysis of network topologies from the point of view of the node protection is needed. The protection strategy can be different from the NEPC based protection. Different strategies should be analyzed.

References

1. M. Ali and J. Deogun. Cost-effective implementation of multicasting in wavelength-routed networks. *IEEE J. Lightwave Technol., Special Issue on Optical Networks*, vol. 18(12):pp. 1628–1638, 2000.

2. J. Doucette, P. A. Giese, and W. D. Grover. Combined Node and Span Protection Strategies with Node-Encircling p-Cycles. In *International Workshop on Design of Reliable Communication Networks (DRCN)*, pp. 16–19. 2005.

3. J. Doucette, D. He, W. D. Grover, and O. Yang. Algorithmic Approaches for Efficient Enumeration of Candidate p-Cycles and Capacitated p-Cycle Network Design. In *Fourth International Workshop on the Design of Reliable Communication Networks (DRCN)*, pp. 212–220. 2003.

4. J. Duato. A Theory of Fault-Tolerant Routing in Wormhole Networks. *IEEE Trans. Parallel Distrib. Syst.*, vol. 8:pp. 790–802, 1997.

5. A. Fei, J. Cui, M. Gerla, and D. Cavendish. A "Dual-Tree" Scheme for Fault-Tolerant Multicast. In *IEEE International Conference on Communications*. 2001.

6. W. D. Grover and J. Doucette. Advances in optical network design with p-cycles: Joint optimization and pre-selection of candidate p-cycles. In *IEEE-LEOS Summer Topical Meeting on All Optical Networking*, pp. WA2–49–WA2–50. 2002.

7. W. D. Grover and D. Stamatelakis. Cycle-Oriented Distributed Preconfiguration: Ring-like Speed with Mesh-like Capacity for Self-planning Network Restoration. In *ICC'98. International Conference on Communications.*, pp. 537 – 543. IEEE, 1998.

8. S. Kini, M. Kodialam, T. V. Laksham, S. Sengupta, and C. Villamizar. Shared backup label switched path restoration. draft-kini-restoration-shared-backup-01, IETF, 2001.

9. A. Kodian and W. D. Grover. Failure-Independent Path-Protecting p-Cycles: Efficient and Simple Fully Preconnected Optical-Path Protection. *J. Lightwave Technol.*, vol. 23(10):p. 3241, 2005.

10. M. Mdard, S. G. Finn, R. A. Barry, and R. G. Gallager. Redundant trees for preplanned recovery in arbitrary vertex-redundant or edge-redundant graphs. *IEEE/ACM Transactions on Networking*, vol. 7:pp. 641–652, 1999.

11. S. Ramamurthy and B. Mukherjee. Survivable WDM Mesh Networks, Part I-Protection. In *INFOCOM '99. Eighteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings.*, vol. 2, pp. 744–751. IEEE, 1999.

12. S. Ramamurthy and B. Mukherjee. Survivable WDM Mesh Networks, Part II-Restoration. In *ICC'99. International Conference on Communications.*, vol. 3, pp. 2023 – 2030. IEEE, 1999.

13. S. Ramamurthy, L. Sahasrabuddhe, and B. Mukherjee. Survivable WDM Mesh Networks. *J. Lightwave Technol.*, vol. 21(4):pp. 870–883, 2003.

14. G. X. Shen and W. D. Grover. Extending the p-cycle concept to path segment protection for span and node failure recovery. *IEEE J. Sel. Areas. Commun.*, vol. 21(8):pp. 1306–1319, 2003.

15. N. K. Singhal, C. Ou, and B. Mukherjee. Cross-sharing vs. self-sharing trees for protecting multicast sessions in mesh networks. *Computer Networks*, vol. 50(2):pp. 200 – 206, 2006.

16. N. K. Singhal, L. H. Sahasrabuddhe, and B. Mukherjee. Provisioning of Survivable Multicast Sessions Against Single Link Failures in Optical WDM Mesh Networks. *J. Lightwave Technol.*, vol. 21(11):pp. 2587–2594, 2003.

17. C.-S. Wu and S.-W. Lee. Backup VP planning for multicast connections in ATM networks. *Computer Communications*, vol. 22(10):pp. 898 – 906, 1999.

18. B. Yener, Y. Offek, and M. Yung. Design and performance of convergence routing on multiple spanning trees. In *IEEE GLOBECOM'94*, vol. 1, pp. 169–175. 1994.

19. F. Zhang and W.-D. Zhong. Applying p-Cycles in Dynamic Provisioning of Survivable Multicast Sessions in Optical WDM Networks. In *Conference on Optical Fiber Communication and the National Fiber Optic Engineers Conference, 2007. OFC/NFOEC 2007.*, pp. 25 – 29. IEEE Computer Society, Washington, DC, USA, 2007.

20. F. Zhang and W.-D. Zhong. p-cycle based tree protection of optical multicast traffic for combined link and node failure recovery in WDM mesh networks. *Comm. Letters.*, vol. 13:pp. 40–42, 2009.

21. F. Zhang and W.-D. Zhong. Performance Evaluation of Optical Multicast Protection Approaches for Combined Node and Link Failure Recovery. *J. Lightwave Technol.*, vol. 27(18):pp. 4017–4025, 2009.

22. F. Zhang and W.-D. Zhong. Extending p-cycles to Source Failure Recovery for Optical Multicast Media Traffic. *J. Opt. Commun. Netw.*, vol. 2(10):pp. 831–840, 2010.

23. F. Zhang, W.-D. Zhong, and Y. Jin. Optimizations of p-Cycle-Based Protection of Optical Multicast Sessions. *J. Lightwave Technol.*, vol. 26(19):pp. 3298–3306, 2008.

24. X. Zhang, J. Wei, and C. Qiao. Constrained Multicast Routing in WDM Networks with Sparse Light Splitting. *IEEE J. Lightwave Technol.*, vol. 18(12):pp. 1917 – 1927, 2000.

25. W.-D. Zhong, F. Zhang, and Y. Jin. Optimized Designs of p-Cycles for Survivable Multicast Sessions in Optical WDM Networks. In *Second International Conference on Communications and Networking in China, 2007. CHINACOM '07*, pp. 473 – 478. IEEE Computer Society, Washington, DC, USA, 2007.

26. F. Zhou, M. Molnar, and B. Cousin. Light-Hierarchy: The Optimal Structure for Multicast Routing in WDM Mesh Networks. In *Computers and Communications (ISCC), 2010 IEEE Symposium on The 15th IEEE Symposium on Computers and Communications (ISCC2010), 2010*, pp. 611 – 616. Riccione Italie, 2010.