Fast and Efficient WDM Network Protection Using *p*-Cycles

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INVITED PAPER

***Abstract*— *p*-Cycles are preconfigured protection cycles for meshed networks. A *p*-cycle protects on-cycle links, and off-cycle links having *p*-cycle nodes as endpoints. For WDM-networks, *p*-cycles can provide fast protection switching times and achieve high resource efficiency.**

***Topic area*: All-Optical Networking**

I. Introduction

p-Cycles provide an attractive way for network protection, since the benefits of both ring-based protection and mesh-based restoration can be utilized [1-5]. In this paper the concept of *p*-cycles for link protection is reviewed. Furthermore results of a case study are presented where *p*-cycles are deployed in WDM networks.

II. The *p*-Cycle Concept

The concept of *p*-cycles can be applied to circuit-switched networks such as WDM networks [2,4]. Two basic types of *p*-cycles exist. Link *p*-cycles protect the individual channels within a link. Node-encircling *p*-cycles are routed through all neighbor nodes of a specific node and protect all the connections traversing this node. The protected node is not contained in the respective *p*-cycle. An emphasis is put on link *p*-cycles, assuming the nodes to be very reliable, e.g., using internal redundancy.

Fig. 1 (a) depicts a network with one link *p*-cycle. The *p*-cycle is able to protect on-cycle links as shown in Fig. 1 (b). Furthermore, a *p*-cycle is able to protect straddling links. A straddling link is an off-cycle link having *p*-cycle nodes as endpoints. In the case of a straddling link failure, a *p*-cycle can simultaneously protect two working paths on the straddling link by providing the two alternative paths around the *p*-cycle as shown in Fig. 1 (c)-(d).

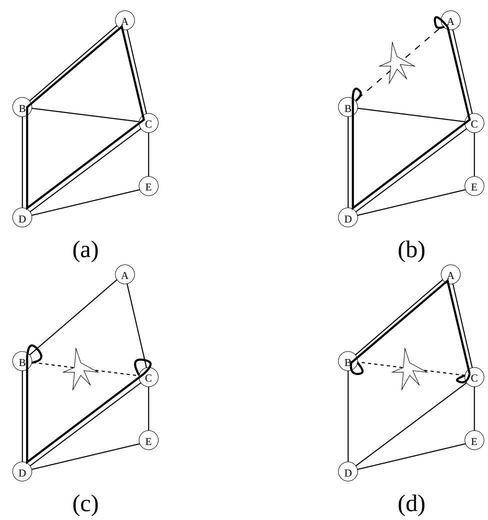

Fig. 1. A network with one link *p*-cycle (a) which can protect on-cycle links (b) and straddling links (c)-(d).

p-Cycles can be installed as a fixed cycle infrastructure in the network. This is similar to the deployment of SDH/Sonet rings, although *p*-cycle nodes differ from ADMs (e.g., by providing ports for straddling links) [2]. Another possibility are virtual *p*-cycles, where the individual cycles are (re-)configurable by a network management system [2,4,5] or by distributed self-organization [1,6].

The network configuration process of *p*-cycles in an existing network can be sketched as follows. First, a given demand for connections is routed through the network, so that the links reserve (working) capacity for the demands. The spare capacity of the links is the remaining available capacity.

Then the *p*-cycles are formed in the spare capacity of the network. The set of link *p*-cycles is chosen such that for every link the working connections are protected by *p*-cycles of corresponding capacity. The routing of the demands has to be adapted, if a protecting set of *p*-cycles cannot be found. Like SDH/Sonet line-switched rings the *p*-cycles protection capacity can also be used for low-priority pre-emptible traffic.

p-Cycles have the outstanding property that protection switching decisions can be made quickly, since only the nodes neighboring the failure need to perform any real-time actions. Switching times in the order of some 10 ms comparable to SDH/Sonet line-switched rings can be achieved.

Therefore, *p*-cycles can be deployed efficiently using non-real-time configuration (centralized network management system or distributed self-organization) while the (distributed, node-internally processed) reaction to failures is very quick.

III. *p*-Cycles for WDM Networks

In the following WDM networks with full wavelength conversion capabilities and WDM networks with no wavelength converters are considered. In the latter case the *p*-cycle length becomes important, because a lightpath can be attenuated too much if it becomes too long after protection switching. Length restrictions also have to be taken into account, if the delay of a connection is limited.

A study of finding an optimal set of *p*-cycles in the pan-European COST 239 network [7] has been performed in [4]. The network comprises 11 nodes and 26 ducts (or spans), where each duct represents two fiber pairs and 128 wavelengths per fiber. The demands of [7] are mapped into suitable lightpath demands and routed by a shortest path algorithm. After a cycle search for all potential *p*-cycles an optimal set of *p*-cycles is determined by a standard integer linear program solver [4].

In summary, the following results are obtained:

- For networks with full wavelength conversion the spare resources used for *p*-cycles of practical lengths (max. 4000-6000 km) consume about half of the capacity compared to the working resources. Non-converting WDM networks reach a spare to working capacity ratio of 71%. Thus, high capacity efficiency can be achieved.
- The *p*-cycle optimization performed better with a demand routing, which tries to achieve balanced load on the links, than a minimum hop routing. However, minimum hop routing is already very efficient.
- Better resource efficiency with increasing permitted length of *p*-cycles.
- The applicability of *p*-cycles is highly dependent on the size of the network. Large length values can introduce too much additional delay for a connection in protection state.
- The *p*-cycles selection process tends to choose cycles with higher number of nodes (see also [8]).
- The configuration calculation time is acceptable for a quasi-online computation, even if reconfiguration after failure is necessary.
- The number of optimal *p*-cycles in the network is in the order of some ten cycles. Therefore, the administrative effort is reasonable.

References

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