Capacity and availability comparison of OMS protection schemes in ASON/GMPLS mesh networks

Luis Velasco, Salvatore Spadaro, Jaume Comellas, and Gabriel Junyent

***Abstract*— Link protection schemes provide high lightpath availability with very limited amount of signaling. When these protection schemes are applied over mesh networks with p-cycles it is also possible to reach service recovery within 50ms after failure detection. In this paper we compare dedicated and shared link protection schemes over mesh-based ASON/GMPLS networks with defined p-cycles. The comparison is performed in terms of traffic capacity and lightpath availability. An analytical model to calculate the lightpaths availability is also discussed.**

***Index Terms*— Dedicated and shared protection, OMS *p-cycles*, ASON/GMPLS mesh networks.**

I. INTRODUCTION

MESH-BASED networks are extensively used in packet-based networks due to their high efficiency and flexibility. Nevertheless, circuit oriented transport networks have been traditionally designed as ring-based networks due to their inherently fast protection switching capabilities and for providing high circuit availability. However, with the introduction of the *p-cycles* concept [1] fast protection is also possible in mesh networks. *p-Cycles* concept can be applied to a wide range of technologies –such as WDM, SONET/SDH, or IP/MPLS networks– and protection schemes –such as path and link protection [2].

Optical Multiplex Section (OMS) protection schemes allow recovering the complete bundle of multiplexed optical channels in a fiber with only one protection action. The GAPS mechanism, based on extensions to the LMP protocol [3], was introduced in [4], [5] for the management of protection in dedicated OMS ring-based ASON/GMPLS networks (OMS DPRing). In [6] the efficiency of OMS protection in terms of protection switching times, protocol simplicity, and scalability was experimentally demonstrated.

In this paper, we extend our previous work studying the lightpaths availability over two different OMS protection schemes (dedicated and shared) for mesh-based networks. Generally speaking, an OMS dedicated scheme is deployed over two-fiber unidirectional networks; one fiber is dedicated to the working traffic while the other is reserved for protection. The OMS shared scheme is deployed over two-fiber bidirectional networks. Let us assume that the total capacity of each fiber is divided in two wavebands: one waveband is reserved to transport working channels, while the other is used to transport protection channels. Thus, working and protection capacities *share* each fiber.

The remainder of the paper is organized as follows: Section II provides an overview of OMS protection mechanisms for mesh based networks. Section III compares the total protected traffic transported in both, OMS dedicated and OMS shared schemes. Section IV studies the lightpaths availability in both schemes, comparing with the obtained in ring-based networks. Finally, in Section V we draw the main conclusions of this work.

II. OMS PROTECTION SCHEMES IN MESH-BASED NETWORKS

A very efficient way of implementing OMS protection schemes in mesh networks is by using *p-cycles* [2]. A *p-cycles* network is a mesh network with pre-connected closed cycles (*p-cycle*) defined on it. One *p-cycle* will include a subset of nodes in the network, and therefore several *p-cycles* can be defined. Links connecting nodes through the *p-cycle* are called *on-cycle* links while links connecting nodes in the *p-cycle* but which are not *on-cycle*, are called *straddling* links. Fig. 1a shows an example of a *p-cycle* network.

On-cycle links have differentiated working and protecting capacity, while straddling links have the double of the working capacity and not protecting capacity.

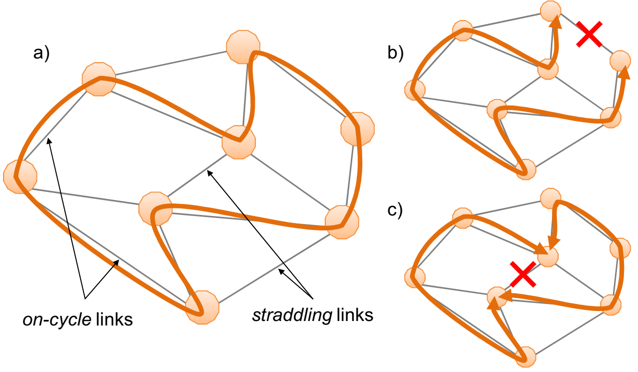

Fig. 1. a) A *p-cycle* network, b) the same network after a failure in an on-cycle link, and c) in a straddling link.

Manuscript received November 19, 2007. This work has been partially founded by i2Cat Foundation through TRILOGY project and by Spanish Science Ministry through TEC-2005-08051-C03-02 RINGING project.

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X. Masip, S.Sánchez, J.Solé, A.Jukan (Eds.): ONDM 2008

This kind of networks presents a better efficiency, in terms of protecting/working ratio, than ring networks. In fact, in ring networks one protecting capacity protects one working capacity, so this ratio is always 100%. In a *p-cycles* network this ratio is lower due to the fact that not only on-cycle links are protected but also straddling links are protected through the on-cycle links. For example, the network depicted in Fig. 1a has a protecting/working ratio of 8/18 = 44.4%.

When an on-cycle link fails (Fig. 1b), its working traffic is protected concatenating the protecting capacity of the rest of on-cycle links. On the other hand, when a straddling link fails (Fig. 1c) two different concatenated routes can be used to protect the link. This is the reason why straddling links can transport double of working traffic than on-cycle links.

In this paper, we define an OMS *p-cycles* network as a *p-cycles* network providing link protection.

The dedicated OMS *p-cycles* scheme (hereafter OMS D*p-cycles*) consists of links on one defined cycle and a number of straddling links (Fig. 2a). In the cycle, the whole capacity of one fiber is dedicated for working traffic while the whole capacity of second fiber is reserved for protection. In the straddling links, the whole capacity of both fibers is dedicated for working traffic.

Both directions of a bidirectional lightpath are routed through the shortest path on the different sides of the cycle or through straddling links. Note than in this scheme, all links are unidirectional. Although straddling links have two working fibers, each fiber transport different lightpaths. An example of this is shown in Fig. 2a, where each direction of a bidirectional path is routed through different straddling links.

When a failure occurs it is detected by the two optical nodes adjacent to the failure. Two cases can arise: if the failure is in an on-cycle link, both nodes loop back the working fiber, containing the affected multiplexed bundle of optical channels, on the protecting fiber in the on-cycle links; if the failure is in an straddling link, one working fiber is protected by the protecting fiber in one side of the cycle, while the second working fiber in the straddling link is protected by the protecting fiber on the other side of the cycle.

In the shared OMS *p-cycles* scheme (hereafter OMS S*p-cycles*), working and protection capacities in the on-cycle links share each fiber. The total capacity of each fiber is divided in two wavebands. The whole capacity of straddling links is for working traffic (Fig. 2b). Working connections in on-cycle and straddling links are protected by the available protecting capacity in the on-cycle fibers.

In this scheme all links are bidirectional, so both directions of a bidirectional lightpath are routed through the same shortest route as shown in Fig. 2b. In this case links transport both directions of bidirectional lightpaths.

When a failure occurs, it is detected by the two optical nodes adjacent to the failure. Both nodes loop back the affected multiplexed bundle of optical channels on the protection cycle in a similar way to the dedicated scheme, switching wavebands instead of fibers.

III. TRAFFIC CAPACITY COMPARISON

In this section, we compare both protection schemes from the point of view of the maximum amount of protected traffic they can transport.

OMS D*p*-cycles networks can be seen as unidirectional cycles and a number of straddling links. The maximum amount of traffic to be allocated on the cycle is limited to the capacity of the links (*W* wavelengths), regardless of the traffic pattern. Adding one straddling link to the network imply to increment the total amount of transported traffic in *W*.

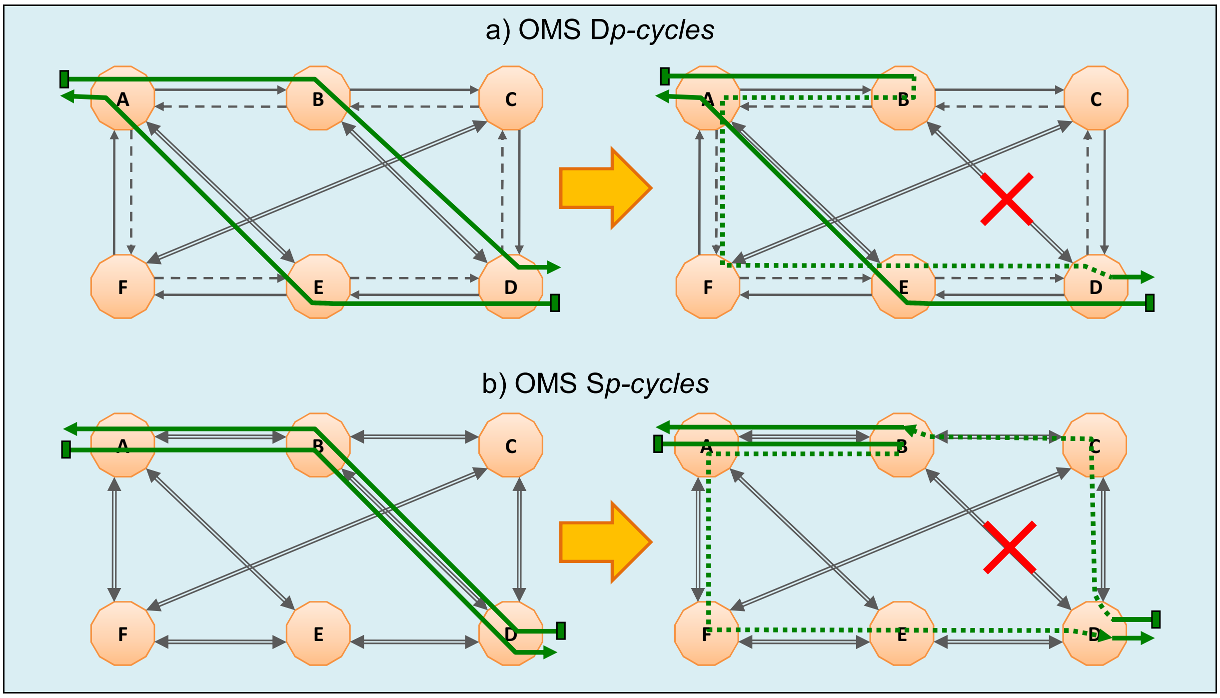

Fig. 2. Examples of OMS Dp-cycles and OMS Sp-cycles networks.

On the other hand, the total traffic transported by an OMS S*p*-cycles network depends on the traffic matrix due to these networks are bidirectional. Therefore, the longer the lightpaths routes are, the larger is the amount of used resources and the lower is the total amount of transported traffic. So, in order to compare the transported traffic we use three different traffic patterns: the hub-like traffic pattern (Fig. 3a), where a single node sources all traffic with the rest of nodes; the full-mesh traffic pattern (Fig. 3b), where all nodes source traffic with the rest of nodes; and the adjacent traffic pattern (Fig. 3c), where all nodes source traffic but only with their adjacent nodes.

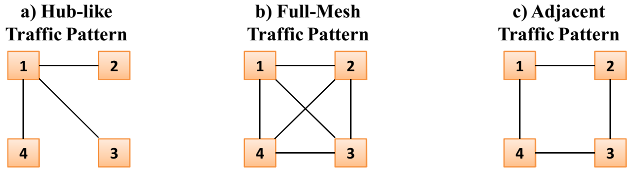

Fig. 3. Traffic patterns.

Let us consider an *n* nodes OMS S*p*-cycles network. In this case, the transported traffic ranges from *W* for the hub-like traffic pattern (as in an OMS D*p*-cycles network) to *Wn/2* for the adjacent traffic pattern. The total amount of traffic for the full-mesh pattern will be in between the two previous cases. Again, adding one straddling link to the network imply to increment the total amount of transported traffic in *W*.

Fig. 4 shows the total transported traffic (number of lightpaths) as a function of the number of nodes (*n*) in the considered network, and for *W=40*. In Fig. 4 mesh networks with 1, 2, and 3 straddling links cases are considered.

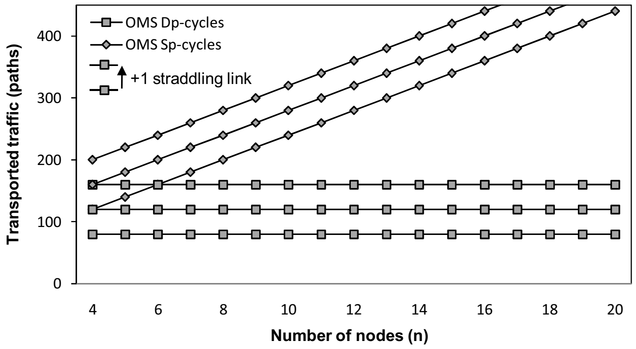

Fig. 4. Total transported traffic (number of lightpaths).

As we can observe in Fig. 4, OMS dedicated protection is a good scheme in networks with a limited foreseen amount of traffic. In networks with a small number of nodes the difference between dedicated and shared schemes is low; by adding straddling links we can transport similar amount of traffic. However, in larger networks shared schemes are able to transport much more amount of traffic due to the way lightpaths are routed.

IV. LIGHTPATHS AVAILABILITY COMPARISON

Lightpaths availability is a crucial aspect when comparing different protection schemes in optical networks. Availability models for some protection techniques in ring-based networks can be found in [5], [7]. For mesh networks, [8] studies the case of link restoration and [9] studies some path protection schemes. In [10] a model to enable *p*-cycles comparison with recovery ring schemes is presented.

In this Section we define a model to calculate lightpaths availability for OMS dedicated and shared protection schemes over *p-cycle* mesh networks, and we will compare the obtained results with those obtained in [5] for OMS dedicated protection in ring-based networks, putting to the test lightpaths availability in ring and mesh networks.

Generally speaking, availability is the probability that a system will be found in the operating state at a random time in the future. According with [2], steady state availability can be expressed as:

$$A = \frac{\text{UpTime}}{\text{UpTime} + \text{DownTime}} \equiv \frac{\text{MTTF}}{\text{MTTF} + \text{MTTR}} \qquad (1)$$

where:

- MTTR: Mean time to repair, the expected time needed to repair the network component.
- MTTF: Mean time to failure, the expected time to the next failure of the network component, following completion of the repair. MTTF is usually expressed in hours or in FITs, number of failures in 10^9 hours.

The probabilistic complement of the availability A is unavailability (U), defined as:

$$U = 1 - A \qquad (2)$$

For the availability analysis purpose, let us consider, for the MTTF and the MTTR, the figures showed in Table 1 [11], [12]. In contrast to metropolitan networks, core transport networks are long-haul networks. In these networks, the system components with highest failure rate are the optical cables (Table 1). Therefore, the availability model can be accurately estimated taking into account only link failures.

TABLE 1 MTTF AND MTTR VALUES

Optical node failure rate	10,867 FITs
Fiber-optic cable failure rate	311 FITs/Km
Plug-replacement Equipment MTTR	2 hours
Fiber-optic cable MTTR	12 hours

Let us denote E_x and $\bar{E}_x$, as an event and a negate event, respectively, associated to a functional element or system *x*. In our study, E_x ($\bar{E}_x$) imply that *x* is (not) operating at the time *t*, independently of the past history of events. Thus, $P\{E_x\}$ represents the x availability (A_x) and $P\{\bar{E}_x\}$ its corresponding unavailability (U_x).

We define the following sets of links: let *P* be the set of all links in the *p-cycles* mesh network; let *C* be the set of on-cycle links; and let *S* be the set of straddling links. Then, $P \equiv C \cup S$, with $C \cap S = \emptyset$. Finally, let *L* be the set of links transporting a particular lightpath.

In OMS D*p-cycles* mesh networks, lightpaths availability is given by the union of three disjoint groups of events: all links $i \in L$ are available; one link in *L* is unavailable, but the rest of the links $j \in P$ are available –links in *C* can be used for protection and links in *S* are not being protected; and, two links are unavailable, one in *S* and in *L* and one in *S* but not in

L and the link in L became unavailable first, the rest of the links $j \in P$ are available. This can be expressed as:

$$P\left\{E^{Dp-cycles}_{lightpath}\right\} = P\left\{ \begin{array}{l} \bigcap\limits_{\forall i\in L} E_i \cup \bigcup\limits_{\forall i \in L}\left(\overline{E_i} * \bigcap\limits_{\substack{p\in P\\ \forall p\neq i}} E_p\right) \cup \\ \cup \frac{1}{2}\bigcup\limits_{\forall t\in L\cap S}\left(\bigcup\limits_{\forall u\in(S-L)}\left(\overline{U_t} * \overline{U_u} * \bigcap\limits_{\substack{\forall p\in P\\ p\neq t,u}} E_p\right)\right)\end{array}\right\} \quad (3)$$

Considering the links in the network as been mutually failure-independent, lightpaths availability over OMS D*p-cycles* mesh networks can be expressed as:

$$A^{Dp-cycles}_{lightpath} = \prod_{\forall i\in L} A_i + \sum_{\forall i\in L}\left(U_i * \prod_{\substack{p\in P\\ \forall p\neq i}} A_p\right) + \\ + \frac{1}{2}\sum_{\forall t\in L\cap S}\left(\sum_{\forall u\in(S-L)}\left(U_t * U_u * \prod_{\substack{\forall p\in P\\ p\neq t,u}} A_p\right)\right) \quad (4)$$

As an example, we will calculate the availability for the lightpath A-D in the OMS D*p-cycles* network shown in Fig. 2a, considering that all links are of the same length (300 km). Then, using the values given in Table 1, the availability will be:

$$A^{Dp-cycles}_{A-D} = A^4_{link} + 4U_{link}A^8_{link} + 1/2*2*U^2_{link}A^7_{link} = \\ = 99.9969\% \quad (5)$$

Availability figures closed to 100% are difficult to compare. For this reason, henceforth we use the unavailability figure. Applying (2), the lightpath A-D unavailability is:

$$U^{Dp-cycles}_{A-D} = 3.122E\text{-}5 \quad (6)$$

The availability of lightpaths over an OMS DPRing network with also six nodes can be calculated using the expression proposed in [5]:

$$U^{DPRing}_{A-D} = 1.876E\text{-}5 \quad (7)$$

This is equivalent to say that the lightpath A-D will be unavailable, in average, 16.41 minutes/year over an OMS D*p-cycles* network or 9.88 minutes/year if we use the OMS DPRing scheme.

In this case, the unavailability is higher than in the ring networks case. This is due to the fact that all links in the network affect the lightpath availability and the mesh network has three additional straddling links with respect to the ring network. To generalize, Fig. 5 shows the effect of increasing the number of straddling links over the unavailability of the longest possible lightpath in OMS D*p-cycles* networks with *n* nodes.

However, the existence of straddling links provides, in general, shortest routes, counteracting in such a way its contribution to the higher lightpath unavailability. In Fig. 6 a comparison between lightpath unavailability in OMS DPRing and OMS D*p-cycles* networks is shown. In the former, all lightpath are routed through the complete ring and thus, all will present exactly the same unavailability. In the latter, lightpaths can be routed through a number on links, which is in general, lower than the previous case. If the end nodes are directly connected through a straddling link, the unavailability will be much better than in the OMS DPRing. On the other hand, if the lightpath is routed through the largest possible route, its unavailability will be slightly worse than in the OMS DPRing. However, in a well planned mesh network routes should be much shorter than in ring networks.

We can use (4) to calculate also the lightpath availability in OMS S*p-cycles* mesh networks, taking into account that, in this case, the network is bidirectional and lightpaths will be routed strictly through the shortest route. In OMS protection, shared refers to the fact that working and protecting resources share one fiber, but every optical channel in a working capacity is assigned a protecting optical channel in the protecting capacity.

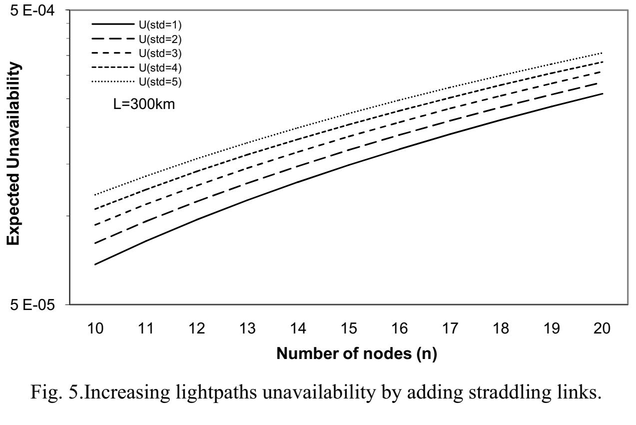

Fig. 5.Increasing lightpaths unavailability by adding straddling links.

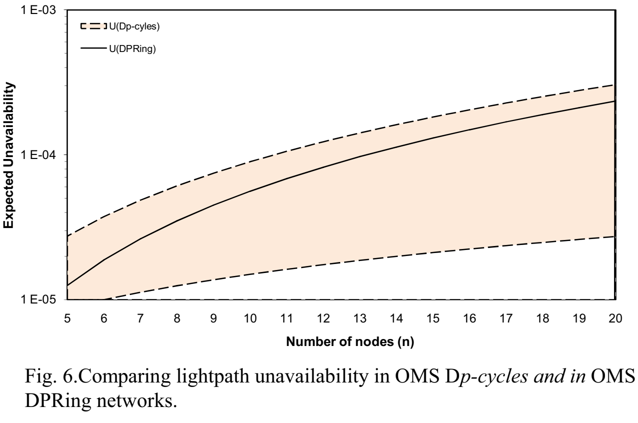

Fig. 6.Comparing lightpath unavailability in OMS D*p-cycles and in* OMS DPRing networks.

In this case, the unavailability for the lightpath A-D in the OMS S*p-cycles* network shown in Fig. 2b, is:

$$U_{A-D}^{Sp-cycles} = 1-(A_{link}^{2} + 2U_{link}A_{link}^{8} + 1/2*2*U_{link}^{2}A_{link}^{7}) = 1.749E\text{-}5 \quad (8)$$

This is equivalent to say that the lightpath A-D will be unavailable, in average, 9.25 minutes/year over this OMS S*p-cycles* network.

On the basis of the previous results, OMS shared protection provides better lightpath availability than OMS dedicated protection, since in OMS shared protection it is possible to find shortest routes for the lightpaths. This is opposite to the path protection, where dedicated path protection provides better lightpath availability than shared path protection due to the protecting route is shared by several lightpaths.

Fig. 7 shows a comparison of lightpath unavailability between OMS D*p-cycles* and OMS S*p-cycles* as a function of the number of nodes in the network. The effect of adding straddling links has been studied above. Here, in order to compare both cases, we assume three straddling links in the network.

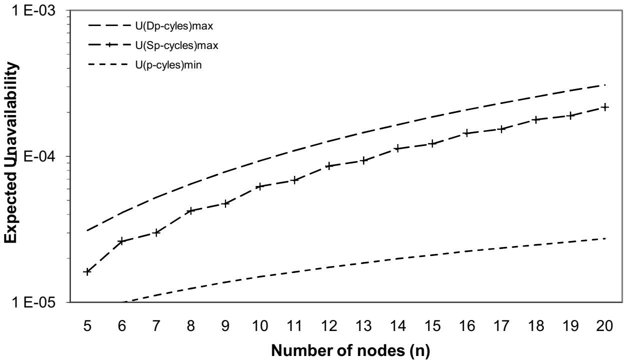

Fig. 7. Unavailability of lightpaths over the two protection schemes.

In OMS *p-cycles*, the unavailability of a lightpath will be some value between the unavailability of the pure straddling lightpath, the minimum, and the unavailability of a lightpath routed through the longest possible path, the maximum. In the case of the pure straddling lightpath, the lightpath unavailability is the same in OMS dedicated and in OMS shared schemes. On the contrary, the worse unavailability is in the case of OMS dedicated scheme, as discussed previously.

Finally, the contribution of the term U_{link}^{2} to the lightpath unavailability is small (≈ 5%). If we do not consider this term to calculate the lightpath unavailability we are assuming that it will become unavailable when two links will unavailable, one of them affecting the lightpath. Therefore, we can consider (9) as being the upper bound of lightpath unavailability.

$$A_{lightpath}^{p-cycles} = \prod_{\forall i \in L} A_i + \sum_{\forall i \in L}\left(U_i * \prod_{\substack{p \in P \\ \forall p \neq i}} A_p \right) \quad (9)$$

V. CONCLUSION

We have compared dedicated and shared protection schemes over mesh networks in terms of lightpaths availability and capacity. Also a model to calculate lightpaths availability has been described for both schemes. The model can be condensed as (9), which is the upper bound for mesh-based OMS *p-cycles* schemes.

In terms of capacity, we can conclude that it is better to use dedicated protection for small networks. Its limiting capacity can be increased by adding straddling links. However, in large networks, shared protection provides higher capacity.

In terms of availability, OMS S*p-cycles* provides better lightpaths availability than OMS D*p-cycles* due to the fact that the lightpaths are routed in the former through a shorter route than in the latter. Moreover, straddling links add an extra unavailability to lightpaths over mesh networks compared with lightpaths with the same number of hops in ring networks. However, the existence of straddling links provides, in general, shortest routes, counteracting the previous statement.

Moreover, mesh OMS *p-cycles* networks present better efficiency in terms of resources needed to protect working resources. We can conclude that mesh networks provide, in much of the cases, better lightpath availability and efficiency than ring-based networks, as they allow lightpaths to be routed through shortest paths.

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