

A network throughput comparison of optical metro ring architectures

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Abstract: We analyze how network throughput degrades in three MAN rings, SONET/SDH, packet-switched, and WDM, following a failure/restoration. For the same ring capacity, WDM rings offer the best network throughput before and after a link failure/restoration.

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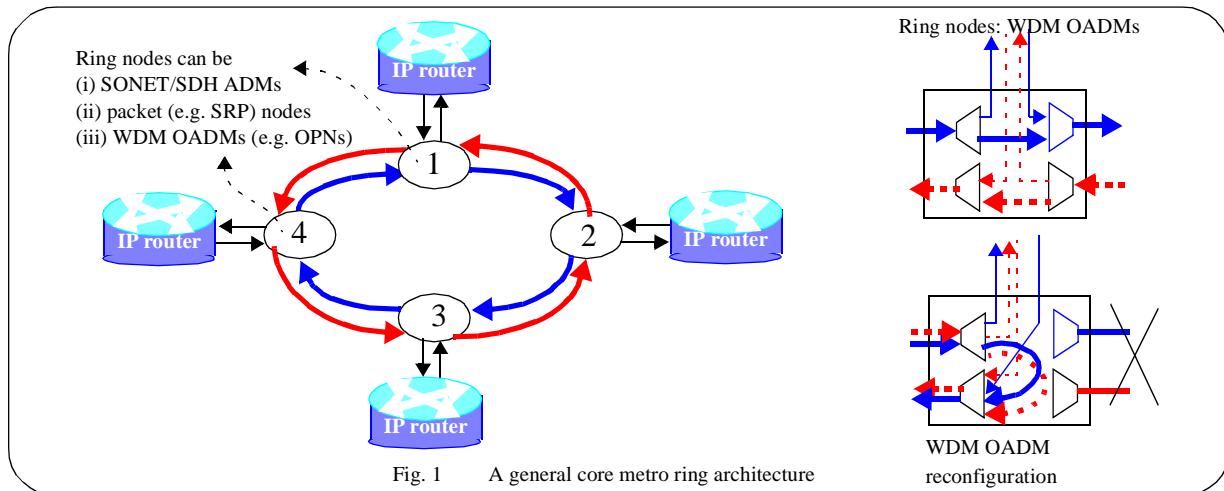
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1. Introduction

Ring based optical Metropolitan Area Networks (MANs) are used to interconnect “network nodes” of service providers as well as “network nodes” of enterprises to those of service providers. For Internet traffic, these “network nodes” are primarily IP routers. A metro ring that interconnects IP routers consists of ring nodes interconnected by optical fiber. These ring nodes can be (i) Synchronous Optical Network/Synchronous Digital Hierarchy (SONET/SDH) Add/Drop Multiplexers (ADMs), (ii) packet switches that implement ring based MAC protocols, such as the Spatial Reuse Protocol (SRP) [1], which is one of the options proposed to the IEEE 802.17 group as a Reliable Packet Ring (RPR) solution, and (iii) Wavelength Division Multiplexed (WDM) Optical Add/Drop Multiplexers (OADMs). Owing to the importance of providing highly reliable service, all three types of ring nodes support fast restoration following fiber cuts or other failures. In this paper, after briefly describing the three rings in Section 2, we analyze the network throughput of the rings before and after a failure/restoration in Section 3.

2. Description of the three ring solutions

The general architecture of a metro ring that interconnects IP routers is illustrated in Fig. 1. As indicated in Fig. 1, the ring nodes could be: (i) SONET/SDH ADMs, (ii) packet (e.g., SRP) nodes, and (iii) WDM OADMs.



In the *first* type of ring, SONET/SDH ADMs add/drop SONET/SDH or lower rate signals to provide connectivity between the IP routers. For example, in an OC12 ring, an OC1 (~51Mbps) signal could be added at the IP router connected to node 1 and dropped off at the IP router connected to node 2 of Fig. 1. SONET/SDH rings are typically of four types: (i) Unidirectional Line Switched Ring (ULSR), (ii) Unidirectional Path Switched Ring (UPSR), (iii) 4-fiber Bidirectional Line Switched Ring (BLSR), and (iv) a 2-fiber BLSR. A ring is *bidirectional* if signals in both directions of a duplex channel travel over the same path, while in a *unidirectional* ring the signals in the two directions of a duplex channel travel over different paths. There are two variants of unidirectional rings: ULSRs and UPSRs. In ULSRs, traffic is only sent on one of the rings, i.e., the working ring. The second ring is reserved as a

“protection” ring, and is used only in case of failures. In a UPSR, to provide path protection for all signals, data is sent on both rings; however, receivers only receive data from one ring (the “working” ring) until a failure occurs, at which point, the protection switch at each ADM decides whether to use data received on the protection ring or the working ring. In a 4-fiber BLSR, two fibers are reserved as a protection ring, while only two fibers are used as the working ring. In a 2-fiber BLSR, being bidirectional, data between two neighboring ring nodes are sent in both directions. But because there is no additional pair of fibers to serve as a protection ring, half the time slots on each fiber are reserved as protection bandwidth. While UPSRs use a path based protection scheme, the three other rings use an Automatic Protection Switching (APS) scheme, which is well summarized in [2].

In the *second* type of ring, ring nodes are packet switches implementing a layer-2 protocol, such as SRP. In an SRP ring, all ring nodes process SRP headers to decide whether to forward the SRP frame on the ring or drop it to the attached IP router. SRP rings typically consist of two bidirectional counter-rotating rings both of which are used to carry working traffic. SRP includes an Intelligent Protection Switching (IPS) procedure to restore the ring by wrapping it around at the two nodes adjacent to the failed link.

The *third* type of rings consist of WDM OADMs, which add and drop wavelengths. Lightpaths are set up through the WDM ring to interconnect two IP routers. An example of such a ring node, called an Optical Packet Node (OPN), is described in [3]. An OPN combines the functionality of an IP router, MultiProtocol Label Switch (MPLS) and WDM OADM. If the nodes of the metro ring of Fig. 1 are OPNs, the “ring nodes” are MPLS switches/WDM OADMs, and the IP router functionality, shown separate in Fig. 1, is merged in with the ring node functionality. Reconfiguration in an OPN ring can take place at the MPLS layer or WDM lightpath layer. For purposes of this paper, we focus on the WDM OADM capability of this node. As in SRP rings, we assume a dual counter-rotating ring. On each fiber, we assume a wavelength allocation scheme in which one half of the wavelengths (say $\lambda_1, \lambda_2, \dots, \lambda_{k/2}$ if k is divisible by two) is set for working traffic in one ring and for protection traffic in the second ring, and the other half (say $\lambda_{k/2+1}, \dots, \lambda_k$) is reserved for protection on the first ring and for working traffic on the second ring. When a link fails, the electronic transmitters at the two IP routers adjacent to the failed link transmit their traffic on to protection wavelengths on both rings, and the electronic receivers at these routers start receiving data from the protection wavelengths (as illustrated on the right hand side of Fig. 1).

3. Analysis

We compare the network throughput of the three rings described in Section 2. *Network throughput* T is defined as the sum total of all traffic that enters the ring at any add/drop node and exits at another add/drop node. The network throughput of a ring depends upon the traffic pattern. For this analysis, we assume a uniform mesh pattern in which every node i sends traffic of non-zero value d to each node j where $j \neq i$, $1 \leq i, j \leq n$, and n is the number of nodes.

Let R be the ring rate. This is the rate at which data is sent on each span (part of the ring between two adjacent nodes) in each direction. For the mesh traffic pattern, $T = 2(n(n-1)/2)d$, where demand d is as shown in Table 1 for the different types of rings. Pairwise demand d is computed by dividing the ring span rate R equally among all demands routed on a span. The number of nodes n can be E (Even) or O (Odd), and demand can be NS (Not Split), S (Split), or D/C (Don’t Care), which means the result is independent of whether the demand is split or not split. Traffic is split equally on the two paths around the rings if the two paths are of equal lengths.

Table 1. Network throughput for different types of rings under the mesh traffic pattern

Ring	d (each non-zero demand)	Network throughput T
ULSR/UPSR	$R/((n(n-1))/2)$	$2R$
4-fiber BLSR	$8R/(n(n+2))$ n: E; demand: NS	$8R(n-1)/(n+2)$ n: E; demand: NS
	$8R/n^2$ n: E; demand: S	$8R(n-1)/n$ n: E; demand: S
	$8R/(n^2-1)$ n: O; demand: D/C	$8Rn/(n+1)$ n: O; demand: D/C
2-fiber BLSR	$4R/(n(n+2))$ n: E; demand: NS	$4R((n-1)/(n+2))$ n: E; demand: NS
	$4R/n^2$ n: E; demand: S	$4R((n-1)/n)$ n: E; demand: S
	$4R/(n^2-1)$ n: O; demand: D/C	$4R(n/(n+1))$ n: O; demand: D/C

Under the mesh traffic pattern assumption, for a unidirectional ring, network throughput is twice the ring rate. For bidirectional rings, for large n , in the 4-fiber case, the network throughput approaches 8 times the ring rate, while in the 2-fiber case, the network throughput approaches 4 times the ring rate. We compared network throughput under other traffic patterns, such a centralized pattern (all nodes send/receive to/from one hub node), and a cyclic pattern (each node sends/receives to/from its neighbors). The results are roughly comparable to those of the mesh pattern.

Following restoration after single fiber cuts, the unidirectional rings and 4-fiber bidirectional ring continue supporting the same network throughput because an equal amount of protection bandwidth lies unused before the cut. For the 2-fiber BLSR case, the network throughput remains the same except when the number of nodes is even and the demand is not split. In this case, curiously, the demand supported before the cut is less than the demand that can be supported after the cut, because $d = R/(n^2/4)$ for even n after the cut (because there is only one route).

The *SRP ring*, being a bidirectional dual counter-rotating ring, is similar to a 2-fiber BLSR. But because the whole bandwidth is used for working traffic (i.e., no bandwidth is set aside for protection unlike in a 2-fiber BLSR), the network throughput is equal to that of a 4-fiber BLSR. After a fiber cut/restoration, the wrapped ring is exactly the same as a wrapped 2-fiber BLSR. Therefore, after restoration, network throughput of an SRP ring drops by half.

In the *OPN architecture*, to make a consistent throughput comparison, we assume that the total transmission rate across half the wavelengths is R . The network throughput of a two-fiber OPN ring is the same as that of a 4-fiber BLSR or SRP ring. After a link failure/restoration, the network throughput remains fully protected (i.e., remains the same) because electronic transceivers at the IP routers now use unused protection wavelengths as illustrated in Fig. 1.

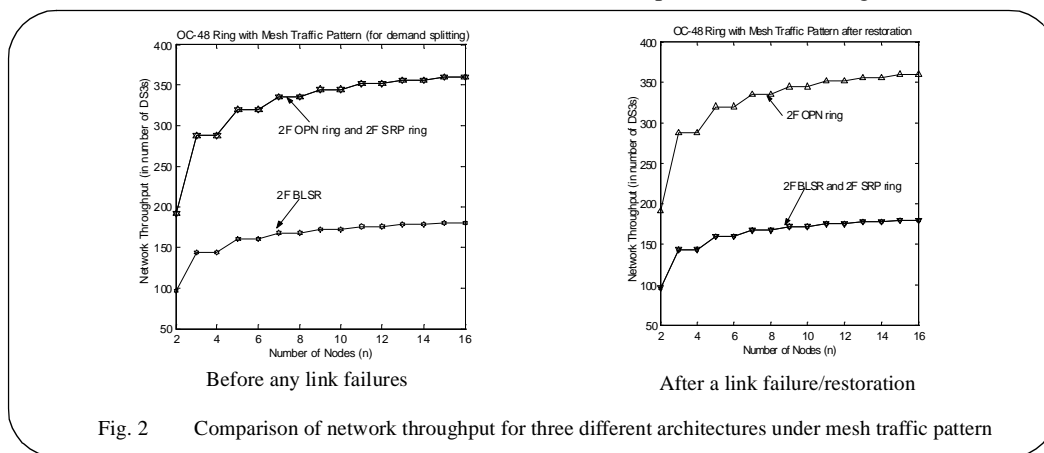


Fig. 2 Comparison of network throughput for three different architectures under mesh traffic pattern

In *summary*, we can compare three 2-fiber (2F) rings: SONET/SDH BLSR, an SRP ring and an OPN ring. We show in Fig. 2, which plots T vs. n , that by using SRP or OPN rings, we can increase network throughput before link failures by a factor of two when compared to a SONET/SDH BLSR. Following restoration after a failure, the throughput of OPN rings remains the same (upper line) while the throughput of an SRP ring decreases to that of the SONET/SDH ring (lower line). While 2F SONET/SDH BLSRs sacrifice network throughput before failures, and SRP rings sacrifice network throughput after a failure/restoration, the penalty paid by OPN rings to maintain the same high network throughput before and after a failure/restoration consists of an extra set of protection WDM filters and switching components. However, as noted in [4, 5], since electronic interfaces are relatively more expensive than optical interfaces, the network throughput advantage afforded by WDM rings comes at a lower cost.

4. References

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