Heuristic method for maximizing the utilization of a survivable multi-ring DWDM network without wavelength conversion

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ABSTRACT

In our paper, we present a heuristic method for maximizing the utilization of a survivable multi-ring DWDM network without wavelength conversion. We assume that the network is supporting packet and circuit based services simultaneously. The idea is that we can provide ample bandwidth or even dedicated channels to packet based services by sharing the resources in the protection ring under normal conditions. In case of a ring failure, the packet based channels can be compressed into fewer channels to yield protection bandwidth to circuit based services. Packet ring technologies such as Resilient Packet Ring (RPR) or IEEE 802.17 will ensure that all packet connections are still maintained in a fair manner under such condition. The main contribution in this work is to jointly consider the effect of packet and optical connection services on DWDM rings to enhance wavelength utilization.

Keywords: DWDM, multi-ring, redundancy, survivable ring, Resilience Packet Ring, wavelength conversion

1. INTRODUCTION

Today, service providers' optical networks often need to carry both circuit based and packet based services.[1] In a traditional ring based network, one ring is dedicated for carrying traffic while a fully redundant ring is on standby for protection purpose. This approach has been entrenched in SONET and it has become the standard configuration to offer guaranteed protection for circuit based network connection.

In a modern network however, there has been a vast increase in the amount of packet based traffic due to the expeditious growth of the Internet. Packet based traffics has been retrofitted into the existing network infrastructure for circuit based services and resulted in bandwidth deficiency. Recent development of new protocols aimed to eliminate the SONET layer for transporting packet traffics on its own ring network while maintaining protection. A successful and commercialised approach is the Resilient Packet Ring (RPR) [2] or IEEE 802.17.

The disadvantage of a traditional survivable ring network is that a protection channel must be dedicated for each working channel [5]. RPR has revoked this disadvantage by putting a healthy ring's protection bandwidth into active service until failure occurs, but its application is limited to packet based ring network.

The latest trend in networking is to exploit the optical layer for multiplying bandwidth.[3] On the optical network layer, circuit and packet based connections can coexist on the same DWDM ring at different wavelengths. To provide wavelength protection on the DWDM ring network is similar to providing protection on a SONET network, that a fully redundant ring is reserved for protection.

When interconnecting SONET rings, add-drop multiplexers (ADM) are relatively inexpensive and readily available. When interconnecting DWDM rings, optical cross connects (OXC) and wavelength converters are typically used [4]. It is often undesirable to deploy wavelength converters because of its complexity and cost. However, the blocking probability of making a wavelength connection across DWDM rings without wavelength conversion will exponentially increase as the number of ring hop increases.[7] We can relieve the bottleneck of hunting an available wavelength for connection across multiple rings by making use of the idle channels on the protection rings.

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Like in the case of RPR, which uses the spatial reuse protocol (SRP) [6], the enhanced bandwidth usage is only applicable when the ring is healthy. In case of a ring failure, all the excess bandwidth usage will fall back to the basics of one wrapped ring under protection mode.

2. METHOD

The proposed heuristic method for maximizing the utilization of a survivable multi-ring DWDM network without wavelength conversion relies on the fact that a network has both circuit and packet service. We define the circuit based services as an end-to-end wavelength connection between two nodes, and we assume the packet traffics are carried by RPRs on a subset of wavelengths. Layer 3 devices interconnect the RPRs for routing packets to another wavelength or another DWDM ring.

Let λ_t be the number of wavelengths on a DWDM ring, and λ_{RPR} be the number of wavelengths used for routing packets on RPR, then the number of wavelengths available for use by circuit based services is $\lambda_c = \lambda_t - \lambda_{RPR}$. On the protection ring, there is an equal number of wavelengths λ_{cp} to protect the λ_c circuits. Note that because of the nature of SRP, λ_{RPR} number of wavelengths is also "in-use" on the protection ring by RPR. Then, the average packet bandwidth on the DWDM ring is $2 \times \lambda_{RPR} \times B$, where B is the bit rate of the RPR channel.

In the proposed method, we make the idle protection wavelengths for circuit based services, λ_{cp}, available for use. We repartition the wavelengths on both active and protection DWDM rings into wavebands for protected (λ_{RPR}, λ_c', λ_{cp}') and unprotected (λ_u, λ_{up}) service. A protected circuit based wavelength connection may hunt for an available channel on either the active or protection ring's waveband, λ_c' or λ_{cp}'. Their protection is handled by λ_{up} and λ_u in the parallel ring. All of the wavelengths on both active and protection ring can be used for handling traffic.

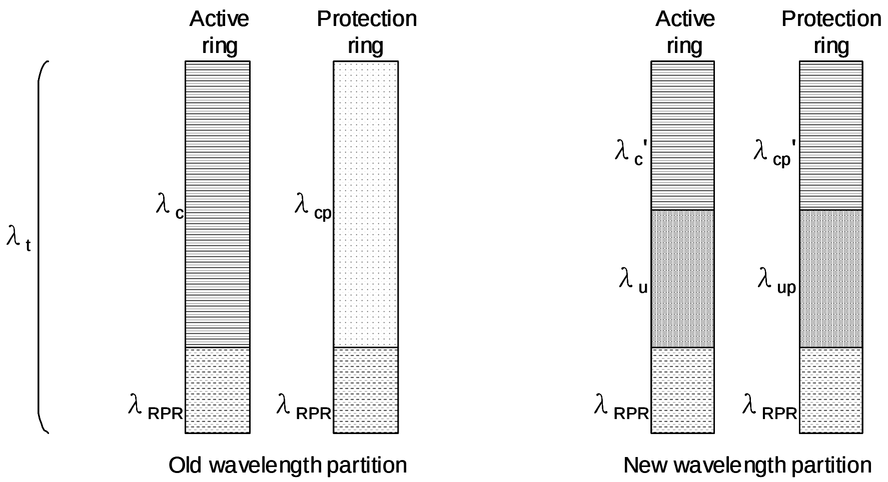

Figure 1, comparison of wavelength partition of the old and new method

The limiting condition to maintain resilience and redundancy is that, the DWDM ring must not support more protected wavelength connections than the number of wavelengths on a single ring, minus the minimum number of wavelengths reserved for RPR ($\lambda_c' + \lambda_{cp}' \leq \lambda_t - \lambda_{RPR}$); and that there must not be an over subscription of QoS guaranteed packet bandwidth, B_{QoS} , on the minimum packet bandwidth under protection mode ($B_{QoS} \leq \lambda_{RPR} \times B$). This is consistent with the fact that there is only one set of working wavelengths on one ring under protection mode.

2.1. Effect on packet based services

Due to the excess in the number of usable unprotected wavelengths, the service provider may choose to route some packet traffic between major nodes on dedicated wavelengths as point-to-point connections. Some high priority packet traffic can also have the benefit of a dedicated point-to-point connection on the available wavelengths. This will relieve the loading on the intermediate layer three routers, and reduces the delay and jitter of the packets. The network will react better to real-time packet services such as voice over IP (VoIP) or video on demand (VOD) because of reduction in the overall congestion and delay.

Since the usage of packet bandwidth can be very flexible, the network service provider may resell a portion of the bandwidth with QoS guarantee, while the excess bandwidth are sold for best effort service only. The total amount of QoS guaranteed bandwidth on the network must meet the limiting condition. With the new method, it is possible to deploy additional RPR on the network using wavelength pairs from λ_u and λ_{up} . Traditional partitioning of wavelengths could not add RPR rings without reducing the wavelength usage on protected circuit based connections.

When the DWDM ring falls into protection mode, the number of wavelengths for packet services reduces to λ_{RPR} again and all the point-to-point packet connections using λ_u and λ_{up} will fallback to RPR mode. Layer 3 routing protocols will reroute the packet traffics while the SRP fairness algorithm (SRP-fa) in RPR will manage the priority of QoS traffic and also allocate available bandwidth to the best effort traffics in a fair manner.

2.2. Effect on optical circuit based services

Under the new partition, there are two wavebands, λ_c' and λ_{cp}', with duplicated wavelengths available for hunting wavelength connections across the network. The greatest benefit is that it will increase the probability of finding an end-to-end available wavelength without wavelength conversion. This is shown by simulation in the following section. In effect, the result is similar to adding an overlay DWDM ring to the network in place of wavelength routing to relieve blocking. In our method, we share the resource from the protection ring to gain the same benefit without increasing the overall cost and capacity of protected circuit connections.

Under the new wavelength partition scheme, unprotected wavelength connection may be handled by λ_u and λ_{up} . They also enjoy the same benefit of lowered end-to-end blocking probability as for the protected connections. The network will yield to protected circuits and drop the connections on λ_u and λ_{up} when it falls into protection mode. Nevertheless, λ_u and λ_{up} may still provide useful bandwidth on a best effort bases under normal conditions.

It is possible to gain on the number of protected circuit connection under the new method if we surrender some protection from the packet service. Normally, λ_{RPR} is provisioned to handle all normal packet traffics. Since there are ample wavelengths for unprotected traffic on the healthy ring, if the provisioning of λ_{RPR} becomes very aggressive to protect the essential QoS guaranteed packet traffic only, then some wavelengths may be shifted from λ_{RPR} to λ_c', λ_{cp}', λ_u and λ_{up} for handling additional protected services. This is feasible to do so if the network restoration time is made sufficiently short to prevent the non-guaranteed packet traffic from extended degradation.

3. SIMULATION RESULTS

We are interested to find out our method’s effect on the protected circuit based connections. It is important to show that when compared with the traditional method, the new method will preserve protection while lowering the blocking probability for an arbitrary set of wavelength connections.[10] The benefit to packet based services is more qualitative and has been discussed in the previous section. Our simulations only consider the effects on circuit based wavelength connection. We used VPItransportMaker™ as our simulation environment.

Simulation was done for two, three, and four DWDM rings networks, each DWDM ring consist of an active ring and a protection ring. The topology under simulation for the four ring network is shown in Figure 2. In all cases, we model each DWDM ring with six nodes. There are two interconnection nodes on each ring that link with its neighbours. All nodes are attached to both the active and protection rings. For the purpose of simulation, we assumed that there are 32 wavelengths on each DWDM ring.

For each network, we simulated four cases under different loading. The base case uses λ_c = 32 wavelengths on the active ring only and serves as the baseline for performance evaluation. We evaluated two cases under the new partition method without wavelength conversion. The 32 active wavelengths were split between λ_c' and λ_{cp}' over the active and protection ring in two partition ratios, 16+16 and 24+8. Their protection is guaranteed by the having $\lambda_{up} = \lambda_c'$ and $\lambda_u = \lambda_{cp}'$. A reference case was done assuming unrestricted wavelength conversion among the 32 is available at the ring interconnection nodes.

The connection demands were created by randomly selecting a pair of nodes, and each connection pair may use up to three wavelengths. VPItransportMaker's internal wavelength routing and assignment (WRA) algorithm was applied to route all the connection demands as they arrive in a random order. It may be possible to obtain better results if the WRA algorithm is optimised.[8,9]

Our simulation program calculates three parameters for comparison amount the different cases investigated. The network utilization index is defined as the sum of the number of wavelengths used on each network segment. The network blocking index is defined as sum of the highest wavelength in use on each network segment. The last parameter is the network efficiency index, defined as the difference between the utilization index and blocking index.

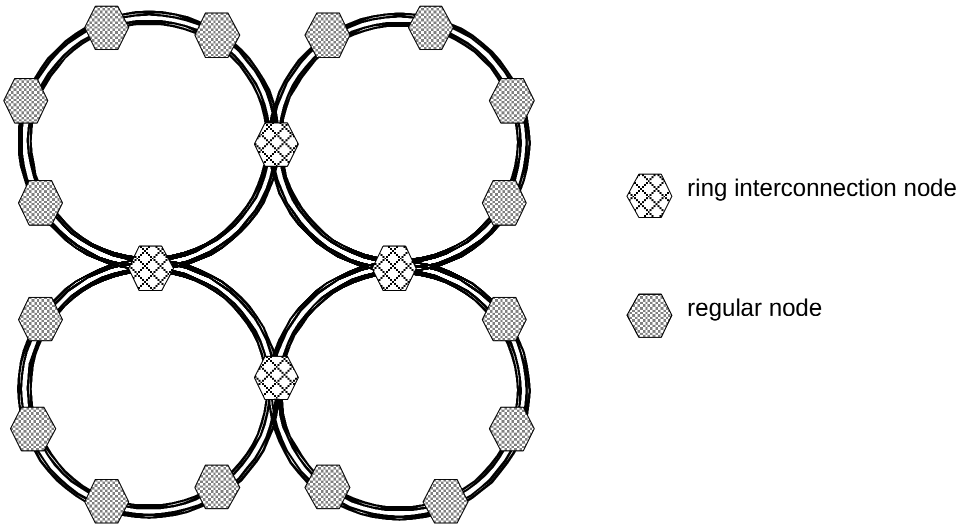

Figure 2, a four ring interconnected DWDM ring network

Since the WRA algorithm in the simulation hunts for the end-to-end available wavelength starting from the lowest number, any gap in the allocation means that a free wavelength could not be assigned because it was not free on some segments in the connection path. When the blocking index is high, it means that the network will be more likely to block new connections. We are not interested to calculate the absolute blocking probability, the blocking index is sufficient for relative comparison amount different cases. If all nodes have unrestricted wavelength conversion capability, the utilization index and the blocking index should be identical, because there will not be any gap in the wavelength allocation table.

Only the charts for the three and four rings network simulation result is shown below for comparison. Result for the two rings network simulations is consistent with the three and four rings network and provides no additional information for interpretation, therefore it is not include here.

The comparison of network utilization index under different loading is show in Figure 3. We can see that there is no significant difference in the network utilization under light connection loading. At high loading when some connections begin to block, the 16/16 partition method and the wavelength conversion solution can achieve a slightly higher utilization because there were more successful connections on the network. In the four ring utilization chart, we can see that the utilization gain begin to close again as the network saturates.

A significant observation is seen in the blocking index shown in Figure 4. The new partition method consistently resulted in lower blocking than the baseline case. Using the wavelength conversion case as reference, the new method results in comparable blocking reduction and even out perform it at very high loading. We made a similar and even more apparent observation from the efficiency index shown in Figure 5. Overall, the proposed method has shown potential improvement in all parameters when compared with the base case. Further more, the improvements shown were comparable or sometimes better than the wavelength conversion reference case.

4. CONCLUSION

Our simulation result has demonstrated that the proposed method to repartition the wavelengths on the active and protection ring is able to make an improvement in the utilization for the protected wavelength connections due to reduced blocking. This observation is important because it is critical to show that redundancy can be maintained while we try to obtain resilience.

The most significant gain on the network utilization actually comes from the flexible use of the unprotected bandwidths. The unprotected wavelengths can be used for packet based services. Packet network protocols such as RPR with SRP-fa algorithm allows the packet connections to be compressed into fewer channels to temporarily yield protection bandwidth to critical QoS guaranteed packet traffic and protected circuit based services. By provisioning just enough protection bandwidth for QoS guaranteed packet traffic only, it is possible to gain more channels for protected circuit connections.

The proposed method benefit on the fact that today's network has a substantial amount of packet traffic. It can realize higher network utilization by jointly considering the effect of packet and optical connection services, and their protection criteria, on a multi-ring DWDM network.

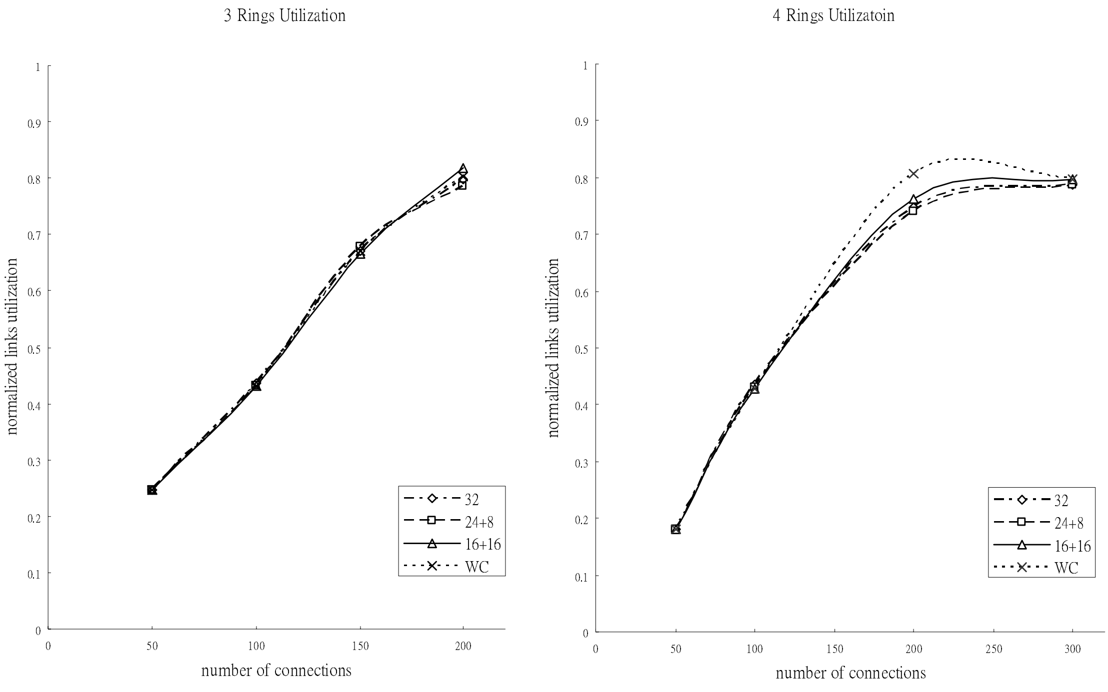

Figure 3, utilization index for three and four ring network

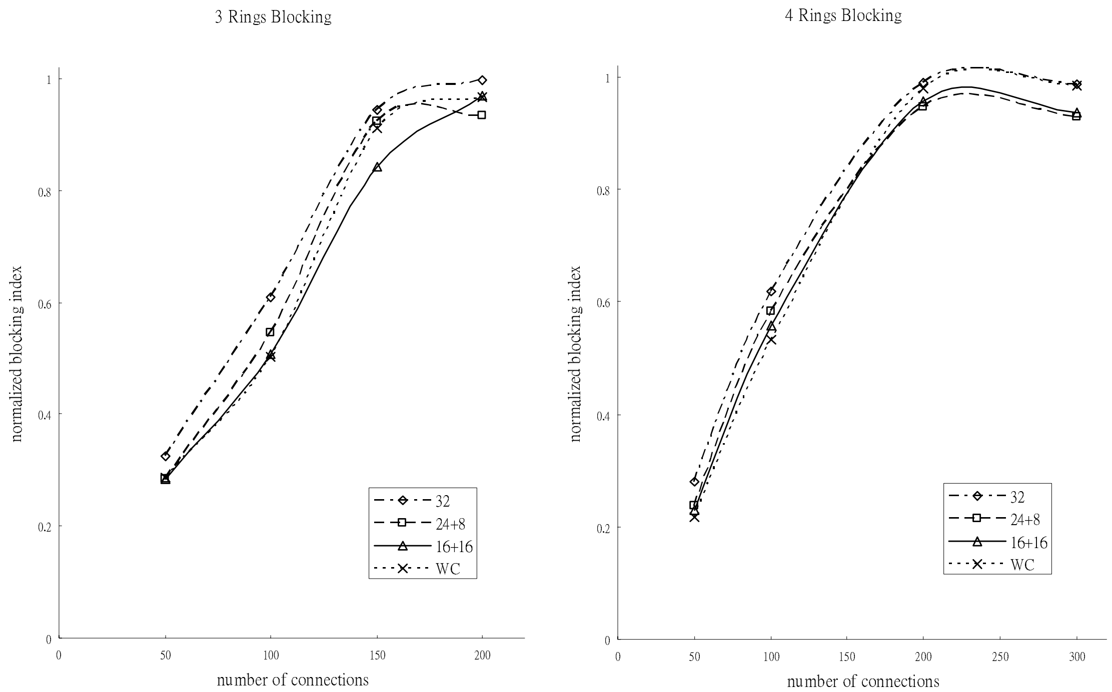

Figure 4, blocking index for three and four ring network

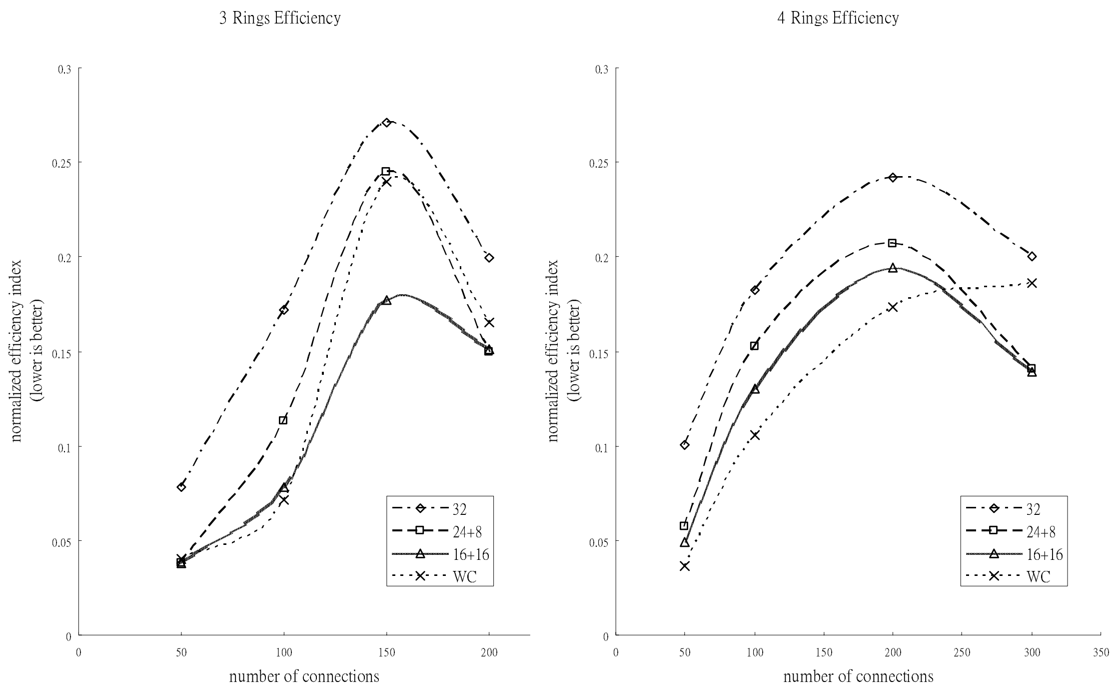

Figure 5, efficiency index for three and four ring network

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