A REVIEW ON PLACEMENT OF WAVELENGTH CONVERTERS IN WDM P-CYCLE NETWORK

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ABSTRACT

The p-cycles can be described as preconfigured closed protection paths in a mesh network. Like rings, the protection path is preconnected in advance of any failure and protection capacity is very fast and simple. And like mesh p-cycle offers the high capacity efficiency. The use of wavelength converter in p-cycle enhances the capacity and rapid protection mechanism for mesh-restorable networks. We can trade- off between costs associated with the number of wavelength converters required and the total spare capacity needed for protection. The most important finding is that the number of wave- length converters can be greatly reduced, with placing wavelength converters at the different points between a transparent optical working path layer and a corresponding set of single-wavelength p cycle protection structures. Here we are comparing different techniques named as sparse, partial and sparse-partial wavelength conversion. The main advantages of sparse partial wavelength conversion technique over the full conversion and no conversion are discussed.

KEYWORDS: *WDM Networks, Sparse Wavelength conversion, Partial Wavelength conversion, p-cycles*

1. INTRODUCTION

The physical wavelength-routed network consists of a set of wavelength routers connected by fiber links. Each fiber link can support a number of wavelength channels using dense WDM technology; wavelength routers can switch the optical signal according to its wavelength. Two wavelength routers can communicate with each other by setting up a "lightpath" in between, which is a direct optical connection without any intermediate electronics. In a word, the wavelength-routed WDM network can provide the circuit-switched lightpath service. A sequence of lightpath requests arrives over time and each lightpath has a random holding time. Due to the capacity limitation of the network, some lightpath requests may not be satisfied, resulting in blocking. One of the primary design objectives in wavelength-routed optical networks is to minimize this blocking probability [1].

p-Cycles offer an attractive option for protection in wavelength division multiplexed (WDM) transport networks, by combining the benefits of both ring-based protection and mesh-based restoration. In a WDM network where wavelength conversion has significant cost, however, the assignment of wavelengths to working paths, and to protection structures, also needs to be considered so that the overall cost of wavelength conversions and capacity is minimized. Wavelength-Division Multiplexing (WDM) in optical fiber networks has been rapidly gaining acceptance as a means to handle the ever-increasing bandwidth demands of network users [2]. In a wavelength-routed WDM network, end users communicate with one another via all-optical WDM channels, which are referred to as lightpaths [3] (Fig. 1). A lightpath is used to support a connection in a wavelength-routed WDM network, and it may span multiple fiber links. In the absence of wavelength converters, a lightpath must occupy the same wavelength on all the fiber links through which it traverses; this property is known as the wavelength-continuity constraint. Figure 1 illustrates a wavelength-routed network in which lightpaths have been set up between pairs of access nodes on different wavelengths.

Therefore, the p-cycle concept in WDM networks with the idea of requiring as few wavelength converters as possible while avoiding any significant penalty in required capacity due to such wavelength-blocking effects is investigated. The new approaches for an efficient configuration are developed and focus on the two aspects of protection capacity efficiency and the number of required wavelength converters is given.

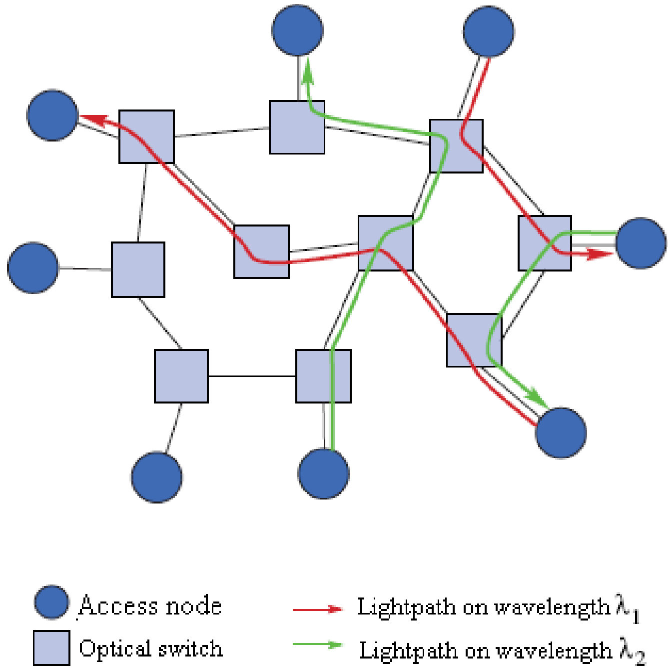

Fig 1: A wavelength routed optical WDM network with lightpath connections

Here, the few terms used in the paper are defined as follows:
Link: Individual wavelength channel between 2 adjacent nodes.
Span: Set of all links between 2 adjacent nodes.
Path: End to end connection described by a sequence of links and nodes.
Wavelength path (WP): Path that consists of links with the same wavelength and thus does not require any wavelength converter.
Virtual Wavelength path (VWP): Path that includes a wavelength converter at each node.

2. THE *P*-CYCLE CONCEPT

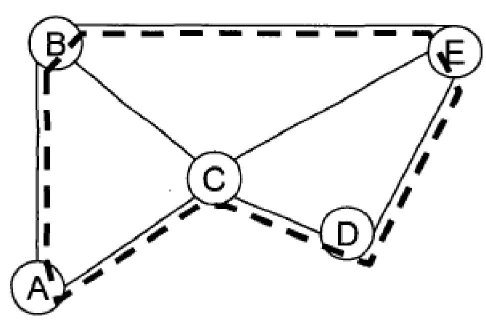

Fig.2. Simple mesh network with one p-cycle

The p-cycle concept, first presented in [4], is a recent strategy to recover from network failures. In fig.2 the dashed line represents a p-cycle of a single unit of protection capacity. It provides a protection mechanism for spans and for transiting traffic through failed nodes. *p*-Cycles can be described as pre-configured closed protection paths in a mesh network. Cycle-oriented pre configuration remains fundamentally a mesh restorable network technology in terms of its capacity efficiency and in its functional differences from self-healing rings. The concept is based on the property of a ring to protect not only its on cycle spans but also the straddling spans.

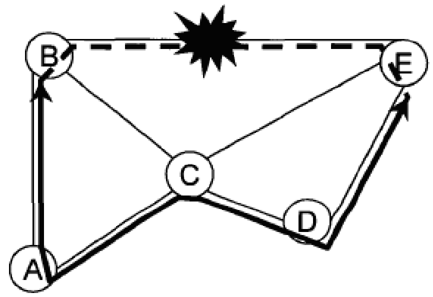

Fig.3. Failure of an on cycle scan

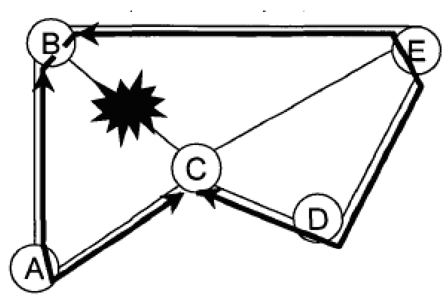

Fig.4. Failure of a straddling span

The p-cycle concept combines the merit of the two basic protection strategies so far known: ring protection and mesh restoration. On one hand, it allows short recovery times of about 50-150 ms known from protection ring structures. On the other hand it has been repeatedly validated that under appropriate design methods, it offers the capacity-efficiency which is essentially as high as that of a span-restorable mesh network. As shown in the fig 3 and fig 4, the p-cycles can protect both an on cycle and straddling span.

3. WAVELENGTH CONVERTERS IN P-CYCLE NETWORKS

When wavelength conversion is not available, a lightpath must use the same wavelength on all the links traversed in a WDM optical network. This requirement is known as the wavelength continuity **constraint**. On the other hand, if wavelength routers are capable of wavelength conversion, an optical signal may be converted from one wavelength to another wavelength. In some previous work on -cycle based protection, a path following the wavelength continuity constraint is called a wavelength path (*WP*), while a virtual wavelength path (*VWP*) is defined to be a path that uses wavelength conversion at each node on the path, and may have different wavelengths on different links that the path traverses. Therefore, a *WP* network has no wavelength conversion capabilities at all, while a *VWP* network has full wavelength conversion at every node, i.e., there are sufficient converters at each node to convert any incoming wavelength to any outgoing wavelength.
Previous research [5], [6] has shown that wavelength conversion enables more efficient resource utilization, and may reduce the lightpath blocking probability significantly by resolving the wavelength conflicts of lightpath routing. However, wavelength converters should not be used arbitrarily due to their high costs, and possible signal quality degradation incurred by some types of converters. Therefore, a tradeoff between the performance of a WDM network, and the number of wavelength converters used exists whether network protection provisioning is considered or not.

4. WAVELENGTH CONVERSION TECHNIQUES

It has been demonstrated that a relatively small number of converters is sufficient for networks to achieve a certain level of acceptable blocking performance. Such networks therefore only have partial wavelength conversion capabilities. The different techniques used for wavelength conversion are as follows:

1. Partial wavelength conversion
2. Sparse wavelength conversion
3. Sparse partial wavelength conversion

4.1. Partial wavelength conversion

WDM networks add the aspect of wavelength assignment to the p-cycle protection concept. Working and p-cycle links may have different transmission wavelengths. It is not sufficient to provide only enough p-cycle protection paths for the working links but its also have to consider the wavelengths of the working paths failed in any given scenario and the wavelength(s) on which a p-cycle is established. If the protection path for a working link is allocated at a different wavelength, the wavelength must be converted to access the p-cycle in case of a failure. Otherwise, all working link and protection path arrangements must be coordinated to have the same wavelengths.

In nodes with partial wavelength conversion, only a limited number of incoming lightpaths can change to a different wavelength on the outgoing link [5] Fig 5 and fig 6 depict an optical cross-connect node with a shared pool of *C* wavelength converters. If there is no wavelength conversion required, an incoming lightpath will be directed to the appropriate output port of an outgoing fiber or to the local access. Otherwise the lightpath can pass through an available converter in the converter pool. As in a WP network there are no converters, and in a highly equipped VWP network each node has at least m*n converters, where m is no. of input and output fibers in the optical switch and n is the total no. of wavelengths in wavelength mux and demux.

With this type of node architecture in mind, it is considered to have two basic alternatives to provide p-cycles in WDM networks with partial wavelength conversion. One employs WP p-cycles with converters used for WP working paths to access them, and the other is based on VWP p-cycles. The first idea is that in order to provide for protection without requiring a set of p-cycles dedicated to every wavelength, but while using as few converters as possible overall, it may be efficient to associate converters only with the p-cycle access points-leaving the working paths to be implemented in a pure WP manner incurring no converter costs. Although in practice the converters may be available for working paths as well, it is assumed for research comparisons on the basic idea that the converters are used for protection paths only. One reason for this is also that protection paths typically need more flexibility in the wavelength selection to be able to protect many working wavelengths. A built-in advantage is also that because a failed working link is replaced by a longer protection path, the converters (which are typically o-e-o regenerative circuits) can ensure that the signal quality of affected paths is not degraded by the protection re-routing. In this basic approach, after detecting a span failure the failure-adjacent nodes switch the working link to a predetermined protection path on a p-cycle and, if necessary, convert the wavelength of the working link to that of the p-cycle at the access point [6].

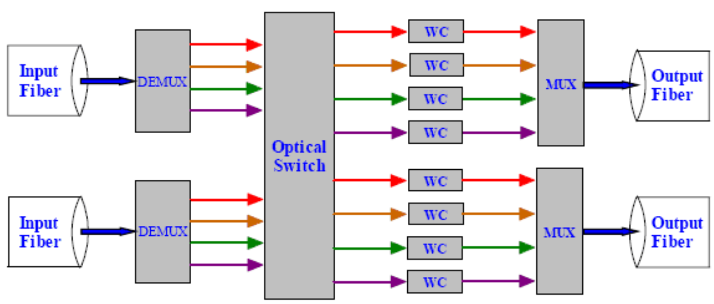

Fig.5. A wavelength converter with full wavelength conversion

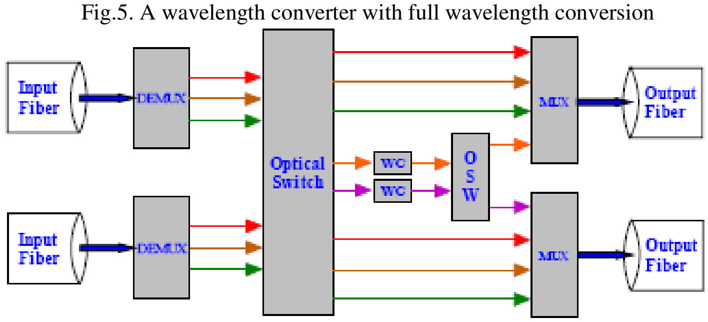

Fig 6: A wavelength converter with partial wavelength conversion

Advantages of partial wavelength conversion:
1. No. of wavelength converters is reduced.
2. Blocking probability of calls is reduced i.e. success probability is increased.

4.2. Sparse wavelength conversion

To achieve the full wavelength conversion capability, i.e. the input wavelength can be converted into any output wavelength; a simple method is to use a converter per wavelength per port in a dedicated manner. However, from commercial point of view this method is not cost effective as the cost of wavelength converters is quite high and also the quality of signal is also degraded. So it is recommended to use the minimum no of converters. To reduce the usage of wavelength converters, there are two approaches [8]. In one approach, sharing of wavelength converters is done through a switch as discussed in the aforesaid approach. Or in another approach, wavelength converters are allocated to only few of the nodes in the network, i.e. some of the nodes possess the wavelength conversion capability while others do not. This refers to sparse wavelength conversion in which only a subset of network nodes have wavelength conversion capability [9,10]. Also the sparse wavelength conversion fulfils the requirement of wavelength conflict rule. According to wavelength conflict rule, the number of wavelengths required in a WDM network is at least equal to the maximal number of channels over a fiber (called maximal link load) in the network . By placing wavelength converters at some nodes in the network (i.e. sparse wavelength conversion), the number of wavelengths needed can be made equal to the maximal link load.
The converter allocation principle is explained with the help of figure 7, 8 and 9. In figure 7 there are two working paths A-B-C and B-A-E and the p-cycle configuration has been completed in the network. In the figure, the shaded nodes indicate the places where converters are needed and the numbers associated with each edge represent the wavelengths assigned to each link passed through the working paths and *p*-cycles.

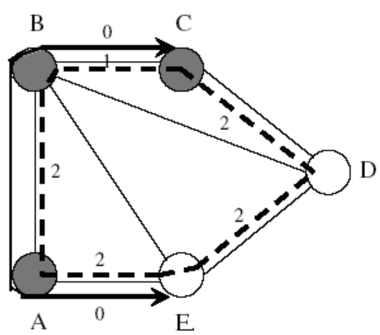

Fig 7: P-cycle configuration in two working paths network

When span ($B - C$) fails, as shown in the figure 8, two converters are needed at node B for the working path ($B - C$) to access the p-cycle (converting wavelength from 0 to 2 and vice versa) as the path is bidirectional and one converter is needed in each direction. If span ($A - E$) fails, similarly, we need not only two converters at node E for the second working path to access the p-cycle, but also two converters at node B and C, respectively, to transmit the on-cycle traffic (converting wavelength from 2 to 1 and then to 2), as shown in fig 9. In the example, node B needs two converters for working path ($A - C$) to access the p-cycle in the case of span ($B - C$) failure, and two converters for on-cycle wavelength conversion in the case of span ($A - E$) failure. Here it may be noticed that to minimize the number of converters, only two converters are needed at node B to protect spans ($B - C$) and ($A - E$) since at most one of the spans may fail at a time in the single failure scenario. Thus in case of sparse partial wavelength conversion, the phenomenon of converter sharing comes in the picture. As per the simulation results [10], the proposed approach significantly outperforms the approach for *WP* networks in terms of protection cost and can obtain the optimal performance as achieved by the approach for *VWP* networks, but requires fewer wavelength conversion sites and fewer wavelength converters.

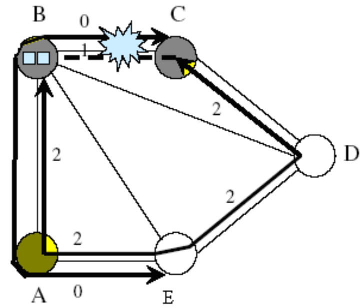

Fig 8: span BC fails

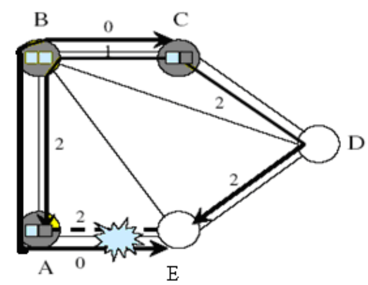

Fig 9: Span AE fails

4.3 Sparse partial wavelength conversion

A special case of partial wavelength conversion is sparse partial wavelength conversion (SPWC) in which only a subset of network nodes is having the wavelength conversion capacity and also the nodes are not fully wavelength convertible. This network architecture can significantly save the number of wavelength converters, yet achieving excellent blocking performance. Though the wavelength converter placement problem has been extensively studied for the Sparse Wavelength Conversion (SPC) case [11,12,13,14], the corresponding problem for the SPWC case is quite different because we need to decide the number of converters for each WCR. Theoretical and simulation results [15] indicate that, the performance of a wavelength-routed WDM network with only 1-5% of wavelength conversion capability is very close to that with Full-Complete Wavelength Conversion capability. Actually the sparse partial wavelength conversion (SPWC) technique combines the benefits of partial wavelength conversion and sparse wavelength conversion. There are two kinds of nodes in the network: common wavelength routers without wavelength conversion capability, and WCRs with partial wavelength conversion capability. By using sparse conversion and partial conversion together, only a small number of wavelength converters are needed to achieve comparable performance as full-complete wavelength conversion. And it only requires that a small fraction of wavelength routers be replaced with WCRs, which is very flexible for the network carriers to migrate the existing network to support wavelength conversion. The SPWC technique can be understood by the following explanation-

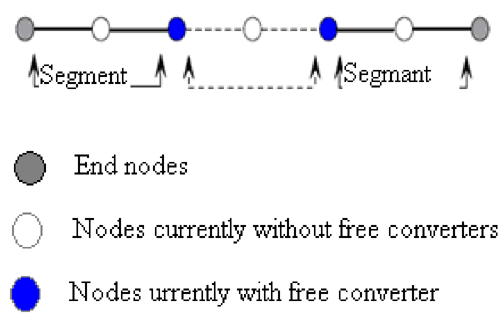

Fig 10: Citation of wavelength converters

Upon arrival of a lightpath request, if there is any link in the selected route having no free wavelength, we have to block this request. Otherwise, we first try to find a common free wavelength on all the links along the selected path. If there is no common free wavelength, we will check whether wavelength converters can help [12]. A lightpath is divided into several segments by the intermediate WCRs which currently have free converters, as shown in Fig. 5. Notice that, a WCR can not provide conversion if its wavelength converters have all been allocated. Each segment still suffers the wavelength continuity constraint because there are no WCRs in a segment (except the two end nodes of the segment). The lightpath can be set up successfully if and only if every segment has common free wavelength(s). So we have to check whether there exist common free wavelengths for each segment individually. Wavelength converters will be allocated if necessary. Once the lightpath is terminated, the allocated converters will also be released. One advantage of the sparse-partial wavelength conversion is its flexibility for the network carriers to install WCRs gradually. As it has been shown in [13], that 90% of the bypassing lightpaths can be set up without wavelength conversion under low traffic, the sparse partial wavelength conversion scheme works efficiently. From the performance analysis [14], it is shown that the performance in terms of blocking probability is very much similar for sparse partial wavelength conversion and partial wavelength conversion, if the total number of wavelength converters is not very large. One advantage of the sparse-partial wavelength conversion is its flexibility for the network carriers to install WCRs gradually [15],[16].

5. PERFORMANCE ANALYSIS OF SPWC ALGORITHM

The Shortest Path Routing and Modified First-Fit (MFF) wavelength assignment algorithm is used for the case with no wavelength conversion, and the Shortest Path Routing and MCA (Minimum Converter Allocation) [17],[18] wave- length assignment algorithm for SPWC. For the network topology in the fig 11, following observations have been made by simulations:

1. full-complete wavelength conversion can decrease the blocking probability by a large margin and
2. Compared to the 1600 converters used in the full-complete wave-length conversion, only 50 converters can achieve satisfactory performance if sparse-partial wavelength conversion scheme is used.
3. MFF wavelength assignment algorithm requires 100 wavelength converters to achieve the best blocking probability, while the MCA wavelength assignment algorithm required only 75 wavelength converters, which means 25% cost reduction.

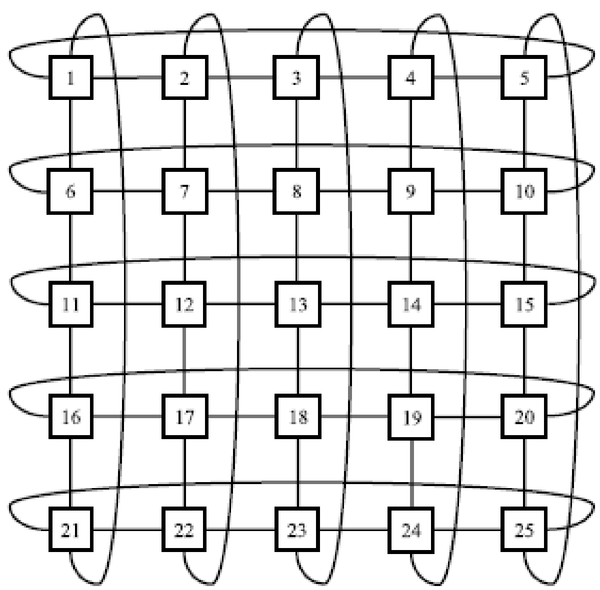

Fig 11: 25 node mesh torus network topology

6. RESULTS:

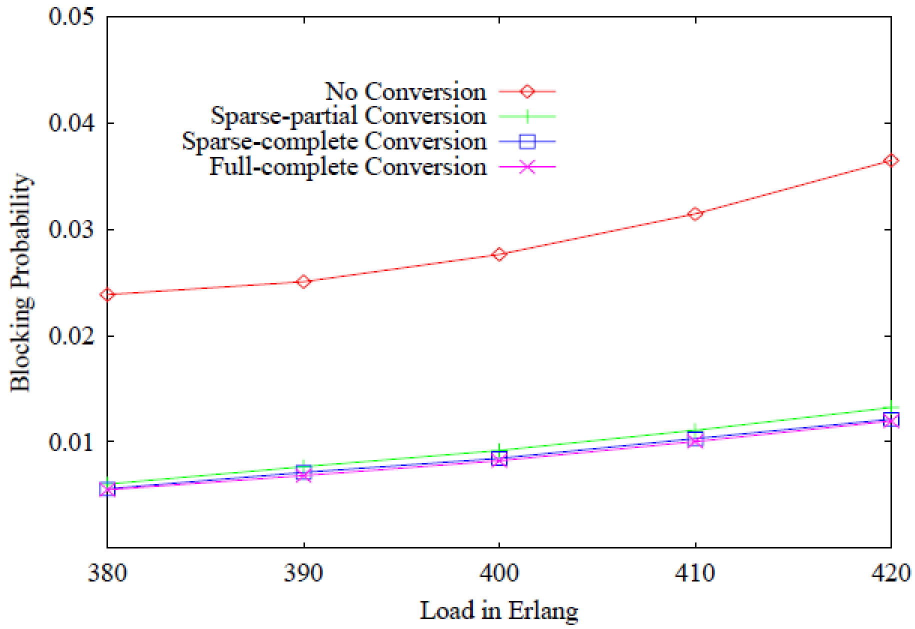

Fig 12: Blocking probability Vs traffic load in a 100 node mesh torus network

In the simulation result [19] shown in fig 12, it can be seen that sparse partial wavelength conversion technique works very well in mesh torus topology. Because of the effect of sparse conversion, 10 WCRs can achieve almost the same performance as 100 WCRs; secondly, because of the effect of partial conversion, only 20 wavelength converters for each WCR can achieve almost the same performance of 160 wavelength converters. Actually this simulation also shows that, if each of the 10 WCRs are equipped with 40 wavelength converters, the performance of sparse-partial wavelength conversion will be the same as that of sparse-complete wavelength conversion. To conclude, only 200 wavelength converters are required for the 100-node mesh-torus network to achieve very close performance to that of 16,000 wavelength converters.
So finally, we can find some results shown in table 1:

Attributes	**Partial wavelength conversion (PWC)**	**Sparse wavelength conversion (SWC)**	**Sparse partial wavelength conversion (SPWC)**
1. Placement of wavelength converters	On all the nodes	Only at few of the nodes	Only at few of the nodes
2. Conversions	Nodes are partially wavelength convertible	Nodes having wavelength converters are fully wavelength convertible	Nodes having converters are partially wavelength convertible.
3. No of converters required for complete conversion (100 node n/w)	1600 converters	200 converters	50 converters
4. Cost	Cost is less as compared to full wavelength conversion	Cost is less as compared to partial wavelength conversion	SPWC technique is most cost effective. Cost can be reduced upto 25% as compared to PWC.

Table 1: Comparison table for the different conversion techniques

7. CONCLUSION

Wavelength conversion has been shown as one of the key techniques that can improve the blocking performance so the success probability in a wavelength-routed all-optical network. Also the wavelength converters are very expensive so to make effective use of the limited number of wavelength converters different techniques are used**.** The different techniques analysed in this paper are partial wavelength conversion, sparse wavelength conversion and sparse partial wavelength conversion. It has been observed that wavelength conversion can decrease the blocking probability by a large margin. The p-cycle concept is a recent strategy to recover from network failures. So the different techniques of wavelength conversion are analysed in p-cycle network. Among all the three, the sparse partial wavelength conversion technique is the best as it comprises of the benefits of both partial wavelength conversion and sparse wavelength conversion. But if we add more wavelength converters into the wavelength convertible routes, the performance of full-partial wavelength conversion can be the same as full-complete wavelength conversion. If the comparison is done between full complete wavelength conversion and sparse partial wavelength conversion schemes, by using SPWC and MCA algorithm, a very small number of wavelength converters can achieve very close performance to that of the Full-Complete Wavelength Conversion.

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