THE CONVERTER PLACEMENT IN WDM NETWORK

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1 Introduction

In recent years, the increasing popularity of the Internet leads to a rapidly rising demand for network bandwidth. Optical networks offer much higher bandwidth than traditional networks due to huge bandwidth of fiber. The currently attracted technology to use effectively the bandwidth of optical fiber is wavelength division multiplexing WDM. The optical spectrum of is divided into a large number of channels on different wavelengths. WDM technology provides transmission on different optical wavelengths through the same optical fiber. We will deal with optical WDM networks only, where each data channel corresponds to a different wavelength. It is known as a *circuit switched optical WDM network* [1]. We also assume that the data still remain between two end nodes in the optical domain. Such a network is called *all-optical* or *photonic networks* [1]. The all optical WDM networks are still very popular for backbone networks with very high transmission rates.

In WDM networks, data can be routed to their respective destinations based on their wavelengths. A network which employs this technique is known as a *wavelength routed network* [1]. In order to transfer data from a source node to end node, a wavelength continuous route has to be set up at the optical layer, which is called a *lightpath*. All lightpaths using the same fiber link must allocate different and distinct wavelengths. It is also known as *distinct wavelength assignment constraint* [1].

The WDM network consists of two types of nodes:

- End nodes (access or edge nodes), which provide the interface between non-optical end systems and the optical systems.
- Optical cross-connects (OXC), which connect the fibers in the networks and provide the switching and routing functions in order to establish the connection between edge nodes.

The OXC consist of space stage and also can include frequency stage for supporting wavelength conversion. The frequency stage is called a *wavelength converter*. In generally, it is a device which is able to switch any incoming optical signal at its port from a wavelength to different wavelength among the available wavelengths from its output port. The OXC could provide a wavelength convertible capability.

In network with no wavelength conversion, the same wavelength must be used on all the fiber links along physical path for establishing a lightpath. This is also known as *wavelength continuity constraint* [1] and such lightpath is referred to as a wavelength path WP. In networks with full wavelength conversion, each node employs wavelength converter and the different wavelengths can be assigned for a lightpath on each fiber link along the physical path. A connection request is accepted if on all the links on its route there is at least one free wavelength.

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2 Limited wavelength conversion [2]

In this section we give a short review of limited wavelength conversion and we concentrate on sparse wavelength conversion. All optical wavelength converters with full range conversion are still very expensive due to technological limitations and it leads to the focus on networks with limited wavelength conversion. In the limited wavelength conversion networks it is allowed conversion but with some restrictions. They can be of following types:

- **a limited range of wavelengths to which an input wavelength may be converted** (it is referred to as *limited wavelength conversion with conversion degree k*)

In general, the limited wavelength conversion with limited range of wavelength conversion with conversion degree k means that any incoming wavelength can be converted to k outgoing wavelengths on output side from wavelength plane of the spectrum. The wavelength plan is an order of all outgoing wavelengths.

- **a limited number of wavelength converters are placed at the node** (it is referred to as *partial wavelength conversion*)

In the case of partial wavelength conversion, the limited number of wavelengths can use wavelength converters at the same time. Only these wavelengths are transported through the converter, which request wavelength conversion. There is a set of wavelength converters (converter bank), which are shared by all the output ports.

- **a limited number of converters at the nodes of the network** (it is referred to as *sparse wavelength conversion*)

If some nodes of the network can provide a wavelength conversion, but not all, it is called a sparse limited wavelength conversion (Fig. 1). In such network there are two kinds of nodes: nodes with two types of wavelength conversion (no, limited or full wavelength conversion). A lightpath must use the same wavelength along each link between two convertible nodes. The set of links between two directly consecutive different types of convertible nodes is called a segment of the path. In generally, there are following possibilities: full – no wavelength conversion, full – limited wavelength conversion and limited – no wavelength conversion.

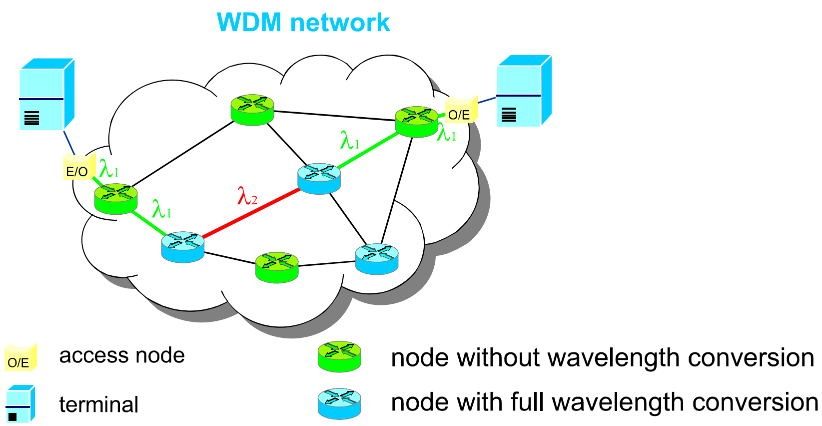

Fig.1 Sparse limited wavelength conversion network

3 Converter placement problem

Although wavelength converters improve blocking performance, the recent research shows that it is not effective to input a wavelength converter to each node in the network. Given the traffic demand, the network topology and the limited number of converters in a network, to decide which network nodes should be equipped with converters in order to minimize the overall blocking probability of the network is called the converter placement problem [1].

The problem of converter placement was first considered in [3]. In [4] a wavelength converter placement heuristic was presented. The detail explanation of converter placement algorithms is out of scope of this paper. In this text we introduce some of the factors which affect the optimal converter placement [1]:

- A node with heavy transit traffic could be a possible candidate for converter placement. However, if it does very little mixing (switching) of traffic, it may not to be good choice for an optimal solution.
- A node which mixes a significant amount of traffic may not be a good candidate for an optimal solution, if the transit traffic at this node is less.
- The distance between two converting nodes is a significant factor in obtaining an optimal solution. The blocking probability increases with increasing distance between two converting nodes.

In a network with arbitrary topology the efficient solution for the problem of converter placement can be obtained by using model by Barry and Humblet, which was presented in [6]. We improved this model for networks with limited wavelength conversion in [7]. We use both model by Barry and Humblet and our model to compute the path blocking probability for two cases of sparse limited wavelength conversion networks: full – no and full – limited wavelength conversion network. In this paper we use the following notations:

W	Number of wavelengths on each link	N	Number of nodes
H	Number of hops of path	n	Number of converters
$l_{i,j}$	Direct link between node i and j	s	Number of segments, if n=0 then s=1 else s=n+1;
a	End-to-end trafic load on path R		
$a^{i,j}$	Amount traffic a going through link $l_{i,j}$	ℓ_j	Diameter of j-th segment, j=1,...,s
$\rho_{i,j}$	Load per wavelength over link $l_{i,j}$	k	Conversion degree

Tab. 1 The blocking probability

	Full – no	Full – limited
Path blocking probability (generally)	$P_b^R = 1 - \prod_{j=1}^{s} \left\{1 - P_b^{seg_j}\right\}$ and $\rho_{ij} = \sum_R a^{ij} / W$	
Segment blocking probability	$P_{b,no} = \left(1 - (1-\rho)^H\right)^W$	$P_{b,lim} = \left[1 - \left(1-\rho^k\right)^H\right]^{W/k}$
Path blocking probability	$P_b^R = 1 - \prod_{j=1}^{s} \left\{1 - \left[1 - (1-\rho)^{\ell_j}\right]^W\right\}$	$P_b^R = 1 - \prod_{j=1}^{s} \left\{1 - \left[1 - \left(1-\rho^k\right)^{\ell_j}\right]^{W/k}\right\}$

We summarize the blocking probability forms in table [1]. For simplicity it is assumed the same link load over all links, i.e. $\rho_{ij}=\rho$ (uniform link load) and the same number of wavelengths on each link. In this model, there are also considered the same independence assumptions as in [6]: Poisson arrival call request, exponential service time, link independence assumption and wavelength independence assumption.

In this section, we give the numeric results. We applied the model by Barry and Humblet and our model for an evaluation of the blocking probability for the single path networks with H=10, N=11, W=15 and k=3. We assume the uniform link load ρ=0.5. In figure [2], the blocking probability is plotted as a function of the number of converters for the best and worst placement of converters in terms of the minimum and maximum blocking probability. From this figure, it can be seen that the blocking probability dependent on the converter placement significantly, while there is a few wavelength converters. It can be also seen the blocking probability will be dramatic degrease if nodes without wavelength conversion are replaced by nodes with limited wavelength conversion. It is also clearly that it is not necessary to use more then 4 wavelengths converter in the networks with 10 hops.

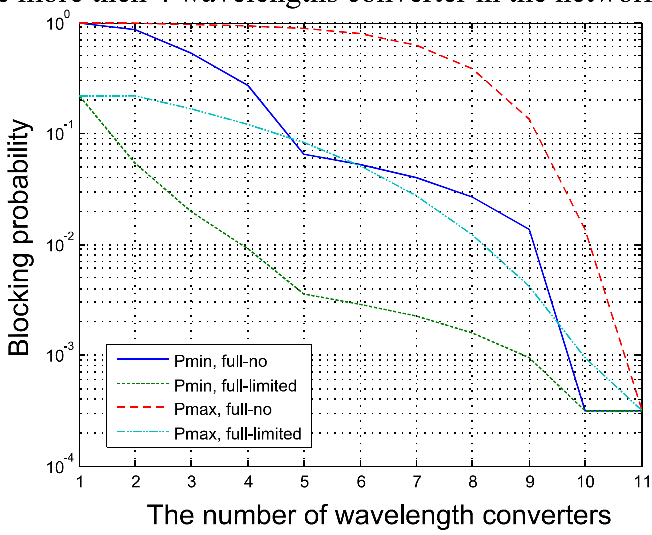

Fig. 2 Blocking probability as a function of number of wavelength converters

4 Conclusion

In this paper we presented the different possibilities of limited wavelength conversion in WDM networks and we concentrated on sparse wavelength conversion and the converter placement problem. We indicated how the placement of wavelength converters affects the blocking probability.

The research in this area leads to determinate the type of wavelength conversion, the placement of converters, the number wavelengths and fibers in order to design optimal networks with respect to customer and operator demands. In future, we will study the limited wavelength conversion cases in detail and we design the blocking probability model for WDM networks. Moreover, we will use this model to determine the optimal placement of converters in sparse limited conversion networks. The simulation results will be performing for different cases of wavelength conversion by VPI simulation tools and compare with the numeric results. Afterwards, based on these results we will optimize today's networks.

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Summarize: *Die Technologie des Wellenlängenmultiplex ist in dieser Zeit ständig beliebte Technologie, welche liefert die effektive Ausnützung der Bandbreite der optischen Fiber. In diesem Dokument präsentiere ich die verschiedenen Möglichkeiten der beschränkten Wellenkonversion in den WDM Netze. In allgemeine, die Wellenkonverteren hebt der Durchlässigkeit des Netzes. Nach der letzten Forschungen ist die Benutzung den Konverteren mit der vollen Wellenkonversion nicht effektiv. Auch ist nicht notwendig, dass die Wellenkonverteren in dem jederen Knoten des Netzes einstellen war. Deshalborientire ich mich auf sparse wavelengt conversion und converter placement problem.*