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MULTICAST CONNECTION CAPACITY OF WDM SWITCHING NETWORKS WITHOUT WAVELENGTH CONVERSION

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Abstract: - In recent trends, many bandwidth applications require multicast services for efficiency matters. Typical multicast applications include video lectures, e-commerce, multiperson conferences and so on. The multicast can be supported more efficiently in optional domain by utilizing the inherent light splitting capability of optical switches than copying data in electronic domain. Wavelength division multiplexing (WDM) technique emerges as a promising solution to meet the rapidly growing demands on bandwidth in present communication networks, supporting multicast. In this paper, the multicast connection capacity of WDM switching networks without wavelength conversion is analysed. Further, the capacity of multistage WDM multicast switching networks and the advantages of multistage switching networks are discussed.

Key Words: - WDM, multicast, switching networks, multicast connection capacity, nonblocking, multicast assignment.

1 Introduction

Multicast communication is becoming an important requirement in high performance networks. This involves the capability of efficiently sending a stream of information from a single source node to multiple destination nodes. Typical multicast applications include tele/video-conferencing and distributive services such as video channels and HDTV program distribution.

Wavelength division multiplexing is an approach that can exploit the huge opto-electronic bandwidth mismatch. The mismatch occurs due to the fact that each end -user's equipment operates only at peak electronic rate. However, multiple WDM channels from different end users may be multiplexed on the same fiber. Under WDM, the spectrum is divided into multiple wavelengths, with each wavelength supporting a single communication channel operating at electronic rate. As WDM technique emerges as a promising solution to meet the rapidly growing demands on bandwidth, and multicast can be supported more efficiently in optical domain by utilizing the inherent light splitting capability of optical switches than copying data in electronic domain, it is important to have an in-depth study on the behaviours of WDM networks under multicast traffic. This topic has recently attracted many researchers into this area [1,2,3].

In all-optical WDM networks, the data remain in the optical domain throughout their paths except at the end nodes. Such paths are termed as lightpaths. In the simplest WDM networks, a connection between two nodes must use the same wavelength within the lightpath. This requirement is known as the wavelength continuity constraint. The wavelength continuity constraint suffers from bandwidth loss. One possible way to overcome the bandwidth loss caused by wavelength continuity constraint is to use wavelength converters at the routing nodes [4]. A wavelength converter is an optical device capable of converting one wavelength to another wavelength. It is true that a wavelength-convertible network performs better than a wavelength-selective network because it relaxes the wavelength continuity constraint at a node. However, in general, wavelength converters are prohibitively expensive.

Jeong et al [5] compared the wavelength-interchanging networks with wavelength selective networks. Karasan et al [6] showed that wavelength selective networks are less complex and do not suffer much performance degradation as compared with the complex wavelength- interchangeable networks. Hence we consider in our analysis, the networks without wavelength conversion.

Leung, Xiao, and Hung [7] proposed node configuration for all-optical multi-fiber networks, which requires small optical switches providing nearly the same blocking probability as the existing node configuration. All these nodes can use the optical switches of the same size, even if they have different number of incoming/outgoing fibers. Miller, Hadas, Barnard, Chang, Dresner, Turner and Hartline suggested that tap-and continue switches can be be used to obtain high-quality multicast virtual topologies. Qin and Yang studied the permutation performance of WDM switching networks in various capacities. Yang, Wang and Qiao also investigated WDM switching networks with no and full wavelength conversion for multicast communication. Most recently, Nagarajan, Savithri and Srivatsa [8] proposed algorithm that results in reduction of wavelengths and hence the number of switches, while studying the performance analysis for shuffle –exchange and Debruijn networks in terms of cost functions. This also proved to be a prime factor for cost effective implementation of those networks.

In this paper, we analyze the multicast connection capacity of WDM switching networks without wavelength conversion. Then we have determined the capacity of multistage WDM multicast switching networks. Finally, the advantages of the higher stages are discussed. The rest of the paper is organized as follows. In Section 2, some necessary definitions for multicast WDM switching networks are provided. Section 3 present analytical methods to calculate the multicast connection capacity without wavelength conversion. In Section 4, the capacity of multistage WDM multicast switching networks and the advantages of multistage switching networks are discussed. Finally the conclusions are given in Section 5.

2. MULTICAST WDM SWITCHING NETWORKS

The WDM switching network consists of N input ports and N output ports is shown in Figure 1. Each port connects to the switching network via a fiber link carrying k wavelengths. We denote the k wavelengths as $\{\lambda_0, \lambda_1, \ldots, \lambda_{k-1}\}$. Also, each input port is equipped with k fixed-tuned optical transmitters, and each output port is equipped with k fixed-tuned optical receivers. The switching unit is assumed to be a crossbar-like switching fabric and is nonblocking from a space-switching point of view. We also assume the switching network is multicast-capable and may be implemented using light splitters, light combiners, and optical cross connect elements such as semiconductor optical amplifier (SOA) gates or micro-electro-mechanical systems (MEMS).

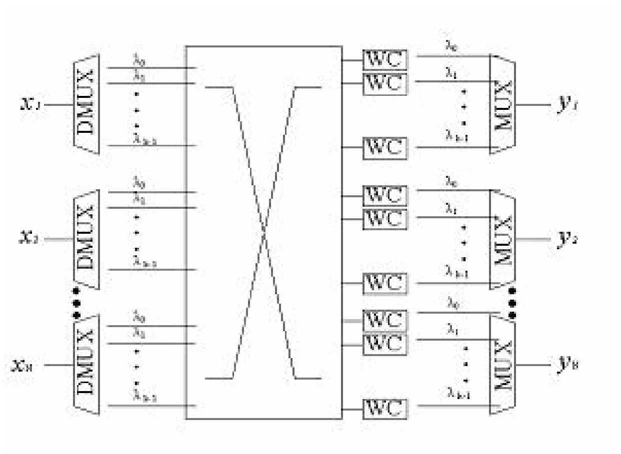

Figure 1. N × N WDM switching network with k wavelengths

2.1 MULTICAST CONNECTIONS

Multicast connections need to be established in an all-optical network when the information from a single source is to be distributed to a number of destinations. Generally speaking, a multicast connection in a WDM network uses a wavelength at an input port and one or more wavelengths at a set of output ports. Accordingly, a node at the input (output) side can be involved in up to multicast connections simultaneously. However, the restrictions are that: 1) a wavelength at an output port cannot be used in more than one multicast connections at a time, or it leads to blocking inherently; and 2) no more than one wavelength at an output port can be used in the same multicast connection (this is referred to as restriction 2), because it is not necessary for an output port to use two or more wavelengths in the same multicast connection.

A set of multicast connections that do not involve the same source wavelength at the input side and the same destination wavelength at the output side is referred to as a multicast assignment. A multicast assignment is called a full-multicast assignment if no new multicast connection can be added to this multicast assignment to form a new multicast assignment. A full-multicast assignment is in fact the maximal set of multicast connections, which can be established simultaneously in a network without conflict. In an N × N k-wavelength network, this means that each wavelength on each output port needs to be connected to exactly one of the wavelengths at the input side.

The above definitions are further clarified with the following example. We have chosen N = 2 and k = 2 in this case and we have two operating wavelengths $\{\lambda_0,\lambda_1\}$. We have assumed no wavelength conversion is possible and hence we can connect only λ_0 (λ_1) at the input side to λ_0 (λ_1) at the output side. We list all six possible connections for output port 1 at the topside of Figure 2 and all six possible connections for output port 2 at the bottom side of Figure 2. A full-multicast assignment for this 2x2 2-wavelength network can be obtained by combining one of the connections for output port 1 and one of the connections for output port 2. Hence, there are 6x6 = 36 full multicast assignments in all. Two such examples are shown in Figure 3. Each of these two full-multicast assignments involves two multicast connections.

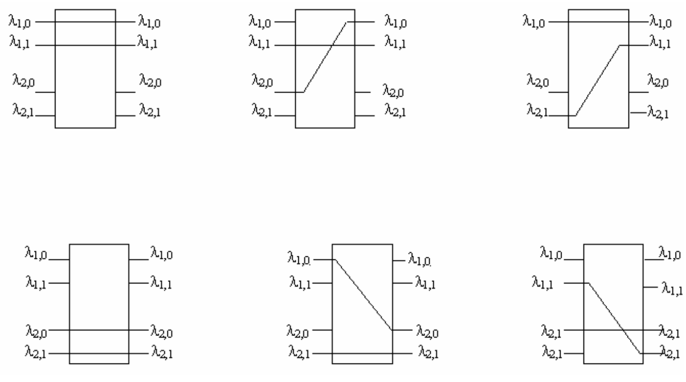

Fig 2 possible connections at the output side for a 2 x 2 2-wavelength network without wavelength conversion

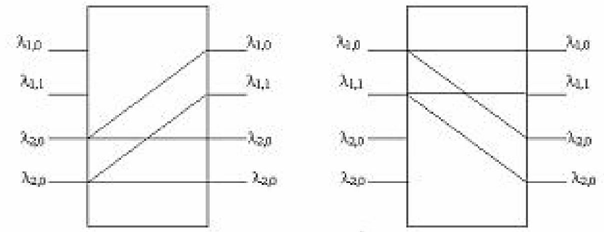

Fig 3 Two examples of full-multicast assignments for a 2 x 2 2-wavelength network without wavelength conversion

Switches with a larger number of full-multicast assignments offer more degrees of connecting freedom to the network, which may improve the network performance. We shall refer to the total number of the full-multicast assignments that a network can realize as multicast connection capacity, or multicast capacity for short, of the network and denote it as M_c.

3 MULTICAST CONNECTION CAPACITY WITHOUT WAVELENGTH CONVERSION

The multicast connection capacity can be calculated as follows. A wavelength converter has conversion degree d (for some integer d, ($1 \leq d \leq k$) if an input wavelength can be converted to d – 1 output wavelengths in addition to the input wavelength itself. When d = 1, no conversion is possible, which means we have to connect the same wavelength in any multicast connection at the input as well as at the output. In other words, λ_0 at input port 1, or 2 or 3 ... or N must be connected to only λ_0 at output port 1. The remaining k – 1 connections (corresponding to the remaining wavelengths from λ_1 to $\lambda_{k-1)}$ in the output port 1 receive connections from any of the input ports in the input side. Suppose that we have connected λ_0 at input port 1 to λ_0 at output port 1, and λ_1 to λ_{k-1} from the same input port 1 to output port 1, and hence k multicast connections are needed. Similarly, when we use wavelengths λ_1 to λ_{k-1} from port 2 for connection to output port 1, we need k – 1 connections (we can not connect λ_0 of input port 2 to λ_0 of output port 1, as λ_0 of input port 1 is already connected to λ_0 of output port 1). If we proceed in this manner, we need totally, N (k – 1) connections (as there are N input ports) apart from λ_0 at input port 1 to λ_0 at output port 1 connection, for N input ports. Likewise, when we take up λ_1 for connection, we need another N (k – 1) connections apart from λ_1 at input port 1 to λ_1 at output port 1 connection for N input ports. In general, for all the wavelengths to be connected at output port 1, we need N (k – 1), N (k – 1),……, N (k – 1) connections for N such ports. Hence the total connections in this case will be N^2 (k – 1). In addition to this, another k connections are needed for λ_0 to λ_{k-1}. Hence, the total multicast connection capacity is

$$M_c = [N^2 (k-1) + k)] \qquad (3.1)$$

The equation (3.1) gives the multicast connection capacity for only one output port (i.e., port 1). Hence, for N output ports, the total multicast connection capacity is

$$M_c = [N^2 (k-1) + k)]^N \qquad (3.2)$$

For example, for a 2x2 2-wavelength network the total numbers of multicast connections are 36

4 MULTISTAGE WDM MULTICAST SWITCHING NETWORKS

WDM switching networks may be implemented by gate switches such as semiconductor optical amplifiers (SOAs) in a broadcast-and select way. Like a crossbar switch, such gate switches are capable of multicast operation. Since optical switching devices are costly, switch fabric realization with a minimum number of these devices are desirable.

In this section, we adopt the well-known Clos network [9] to provide a cost effective solution to WDM multicasting without wavelength conversion. The Clos-type network has adjustable network parameters and can provide different types of connecting capabilities by choosing different values of the parameters. A three- stage Clos network with N input ports and N output ports is shown in Figure 4.

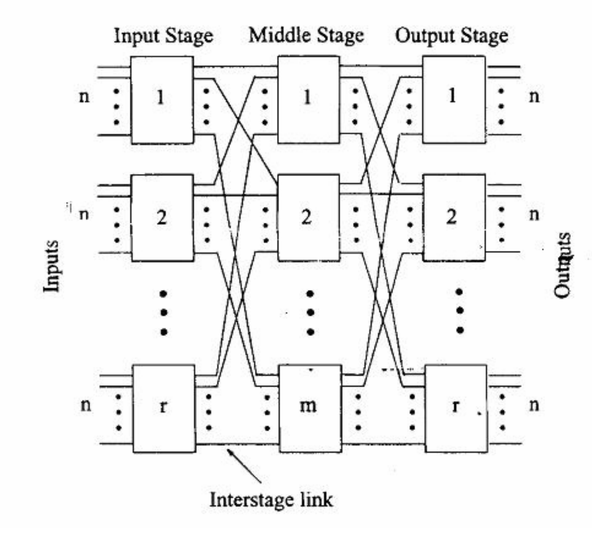

Fig 4. Three-stage switching network

This has r switch modules of size r x r in the middle stage, and r switch modules of size m x n in the output stage with $N = nr$ and $m \geq n$. The network has exactly one link between every two-switch module in its consecutive stages. Such a three-stage network is conventionally denoted as v (m, n, r).

It is easy to see that the network cost of a v(m,n,r) network is proportional to the number of middle stage switches m for a fixed N and r. A critical issue in designing such a network is how to ensure that the network is nonblocking, and at the same time, minimizing the number of middle stage switches m, hence reduce the cross points.

We now determine the number of crosspoints required for a single stage and a three-stage network. A single-stage network has the capacity of N^2 whereas a three-stage network has the capacity of $4N\sqrt{2}\sqrt{N}$.

Table 1: Number of connections for single stage and there stage networks

Number of ports	Connections for Single Stage	Connections for Three Stage
128	16384	8192
2048	4 million	0.5 million
8192	64 million	4 million
32768	1 billion	32 million

The following advantages are noticed in the three-stage network as compared to single-stage network. It reduces the number of crosspoints. The alternate crosspoints and paths are available.

5 Conclusion

In this paper, we have analysed the multicast connection capacity of WDM switching networks without wavelength conversion. We have also discussed the capacity of multistage WDM multicast switching networks and the advantages of multistage switching networks.

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