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Blocking probability calculation in wavelength-routed all-optical networks

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ABSTRACT

In this paper we have proposed a mathematical model to reduce the blocking probability of the WDM optical network. The mathematical model proposed has a closed-form expression and does not require simulated statistics, it has low implementation complexity and the computation is quite efficient. This model suggests us to choose the best path and appropriate number of free wavelengths in the network. We can go for the compromise between the path length and number of free wavelength. The model is also used to evaluate the blocking performance of NSFNet topology and hence used to improve its performance.

1. Introduction

The optical fiber has extremely high bandwidth in the low attenuation band, and this is 1000 times the total bandwidth of radio on the planet earth [1]. However, only speeds (data rates) of a few gigabits per second are achieved because the rate at which an end user can access the network is limited by electronic speed, which are a few gigabits per second. Hence it is extremely difficult to exploit all of the huge bandwidth of a single fiber using a single high-capacity wavelength channel due to optical–electronic bandwidth mismatch or "electronic bottleneck". The recent breakthroughs are the result of two major developments: *Wavelength Division Multiplexing* (WDM), which is method of sending many light beams of different wavelengths simultaneously down the core of an optical fiber; and *erbium-doped fiber amplifiers* (EDFA), which amplifies signals at many different wavelengths simultaneously, regardless of their modulation schemes or speed. In WDM each wavelength can carry data modulated at several gigabits per second and it is feasible to have simultaneous transmission of hundreds of wavelengths in the low-attenuation 1550 nm window of standard single mode fiber. Sitting in the heart of WDM is the routing and wavelength assignment (RWA) problem [2]. Routing and wavelength assignment problem can be defined as; *given the network topology and a set of end-to-end lightpath requests, determine a route and wavelength(s) for the requests, using the minimum possible number of wavelengths*. Routing and wavelength assignment problem is one of the main important problems of WDM optical networks. In literature there are a number of methodologies proposed to tackle the RWA problem. One method is to consider the RWA problem as a coupled RWA problem (single compete problem) and the other method is to divide this RWA into the two sub problems i.e. *Routing problem* and *wavelength assignment problem*. The solution obtained by dividing this problem in sub problems is sub optimal but is practical to use [3]. The blocking probability of a lightpath request (or a call) is an important performance measure of a wavelength-routed network. This blocking probability can be affected by many factors such as network topology, traffic load, number of links, algorithms employed and whether wavelength conversion is available or not. WDM link can be easily illustrated by Fig. 1.

Today's widely installed WDM optical networks are opaque, that is, a signal path (connection) between any two end nodes or users in these networks is not totally optical. This means the path involves optical–electronics–optical conversion operations at intermediate nodes and these conversion operations affect the network speeds or the bit rates. WDM optical networks are migrating from just point-to-point WDM links to *all-optical* networks, where more and more switching and routing functions are carried out in optical domain. In all-optical networks each connection (lightpath) is totally optical except at the end nodes. Optics is clearly the preferred means of transmission, and WDM transmission is now widely used in the network. In recent years, the people have realized that optical networks are capable of providing more function that just point to point transmission. Major advantages are to be gained by incorporating some of the switching and routing functions that were performed by the electronics into the optical part of the network. In the first-generation optical networks, the electronics at a node must handle not all the data intended for that node but network. If the latter data could be routed through in the optical domain, the burden on the underlying electronics at the node would be significantly reduced. This is the one of the key driver for the second generation optical networks [4]. The optical networks based on this paradigm are now being deployed. We call this network

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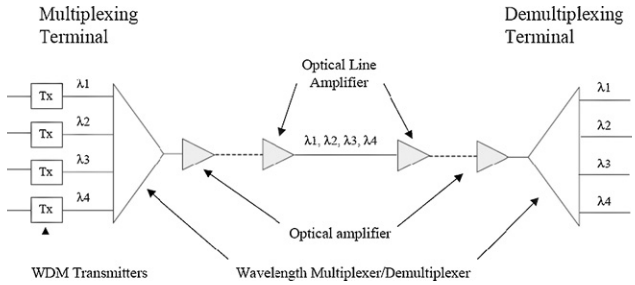

Fig. 1. A typical WDM link.

as *wavelength-routed* optical WDM network. One such network is shown in Fig. 2.

The key network elements that enable optical networking are *optical line terminals* (OLTs), *optical add/drop multiplexers* (OADMs), and *optical crossconnects* (OXCs). An OLT multiplexes multiple wavelengths into a single fiber and demultiplex a set of wavelengths on to a single fiber into separate fibers. OLTs are used at the ends of point to point WDM link. An OADM takes in signals at multiple wavelengths and selectively drop some of these wavelengths to the composite bound signal. An OADM has two line ports where individual wavelengths are dropped and added. An OXC essentially performs a similar function but at much larger sizes. OXCs have a large number of ports (ranging from few tens to thousands) and are able to switch wavelengths from one input port to another. The network provides *lightpath* to its users, such as SONET terminals or IP routers. Lightpaths are optical connections carried end to end from a source node to destination node over a wavelength on each intermediate link. An intermediate node in the network, the lightpath are routed and switched from one link to another link. In some cases, lightpaths may be converted from one wavelength to another wavelength as well along their route. Different lightpaths in a wavelength routed network can use the same wavelength as long as they do not share any common links. This requirement that the same wavelength must be used on all the links along the selected route is known as *wavelength continuity constraint*. Two lightpaths cannot be assigned the same wavelength on any fiber. This requirement is known as *distinct wavelength assignment constraints*. However, two lightpaths can use the same wavelength if they use disjoint set of links. This property is known as *wavelength reuse*. Wavelength reuse in wavelength routed network makes them more scalable networks than other networks. The performance of the routing and wavelength assignment algorithms is calculated in terms of blocking probability and fairness. We can also have wavelength conversion if we have wavelength converters as a part of the network. Wavelength conversion can eliminate the wavelength continuity constraint and can thus improve the blocking performance significantly [5]. Since the wavelength converters are very expensive nowadays, much research work focuses on *sparse wavelength conversion*, in which only a part of network nodes have the capability of wavelength. If all the network nodes have the capability of wavelength conversion, this is referred to as *full wavelength conversion*. There are a number of models covered in the literature for calculation of blocking probability of optical networks. The blocking probabilities of optical network models for the schemes: fixed routing and least-loaded routing are calculated by using generalized reduced load approximation techniques in [6]. Many mathematical models [5–7] have been proposed in the literature but some of them are complex in nature also high simulation statics are required in those models. The model proposed in this paper is a low complexity model which is very useful for the calculation and reduction of blocking probability of the network which can also be used for the wavelength convertible networks as well as for wavelength non-convertible network. Also, this model does not require any simulation statistics.

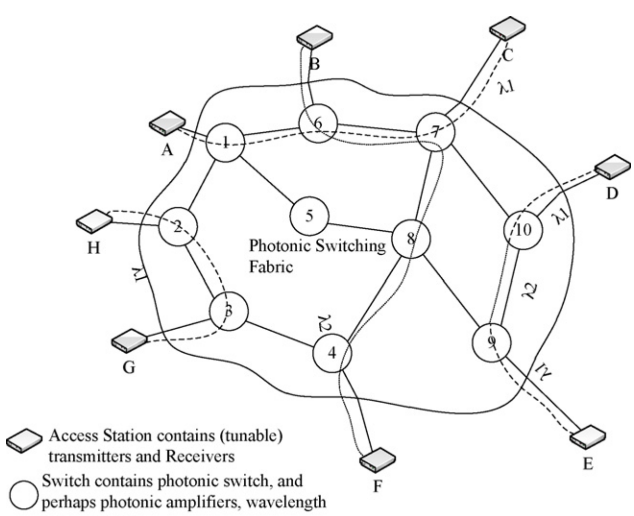

Fig. 2. Wavelength-routed WDM optical network.

This paper is organized as follows: In Section 2, we have proposed a mathematical model for a WDM optical network. Section 3 focuses on the results and discussion, which shows simulation results by taking the realistic NSFnet networks. Conclusions are covered in the Section 4.

2. Mathematical model

We have denoted the path and the network-wide parameters by upper-case letters and link parameters by lower case letters. Subscripts and superscripts refer to specific instances of links, node pairs and routes.

2.1. Notations used

We have used following notations:

- s and d denotes source and destination of an end-to-end traffic request. The end-to-end traffic may traverse through a single lightpath or multiple lightpath.
- N: number of nodes in the WDM network.
- l: number of links in the route or path selected, and all links have C channels.
- r: number of routes available where $r \in R$.
- $B(C, L_{sd}^r)$: Erlang loss formula for L_{sd}^r load and C channels.
- B_{sd}: blocking probability; $B_{sd} = 0$ if the request from node s to node d has been successfully routed; otherwise, $B_{sd} = 1$, call blocked.
- B_{sd}^r: blocking probability of r routes.
- L_{sd}^r: load of the route r.

2.1.1. Objective

To develop a mathematical model that is suitable for any network, for calculation and minimization of blocking probability.

2.2. Proposed model

2.2.1. Given

- **N** node WDM network.
- All the nodes forms a set **V**.