MNCASS - A Spectrum Resource Allocation Algorithm For The Flexible Bandwidth Optical Network

Junjun Xu, Yongli Zhao, Bingyu Li, Kangjing Song

Abstract: In a flexible bandwidth optical network, the necessary spectrum resources on a given route are sliced off into small slots from the available pool and adaptively allocated to the end-to-end optical path according to the client data rate and the available spectral resources. And efficiently assign spectrum slots would decrease the light path blocking probability and enhance the network performance. In this paper, we first defined a measurement parameter called contiguous spectrum segment value as the objective value during the resource allocation procedure, then we developed a novel spectrum resource allocation algorithm called MNACSS (Minimum Number of Available Contiguous Spectrum Segments) which based on the FF (first fit) algorithm. The simulation results show that MNACSS has a lower blocking probability when compared with First Fit allocation algorithm.

Index Terms: Spectrum resource; Flexible bandwidth optical network; Contiguous spectrum segment; First Fit; SLICE; DWDM; Optical Switch.

1 INTRODUCTION

TRADITIONAL fixed-sized spectrum resource allocation method requires assign a whole wavelength to an optical path no matter the traffic volume of the light path which leads to resource wasting problem. The proposed technology SLICE (spectrum-sliced "elastic optical path" network) offered a new way to allocate spectrum resource efficiently. In SLICE a whole wavelength is separated into numbers of continuous spectrum slots, then the SLICE optical path can add or drop slots according to the client traffic volume, for example, it can use 3 slots to transmit the 30Gb/s traffic volume and use 5 slots to transmit the 50Gb/s traffic, it doesn't need to use the whole resource to transmit the client traffic, and at the same time the remaining slots can be used for other data services. The division and reassemble of spectrum slots provide a way to implement the flexible bandwidth optical network, but it requires an appropriate spectrum resource allocation algorithm to implement dynamic bandwidth allocation. According to paper [5], there are two main constrains when designing spectrum resource allocation mechanism the frequency continuity and consistency constrains. Under these constrains, we will focus on finding an effective way to assign the spectrum resources to provide a lower blocking probability, and at the same time a tradeoff should be made between algorithm complexity and efficiency. The content structure of this paper is organized as follows, in section two background knowledge and some definitions are presented. In section three, we use the mathematical model to analysis the spectrum resource allocation problem and then we introduced the MNCASS algorithm. In section four we presented the simulation result. Finally is the conclusion part.

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2 BACKGROUND KNOWLEDGE

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]. Based on WDM the so called DWDM (Dense WDM) technology has been put forwarded. DWDM performs an inherent flexibility. Researches have demonstrated that the number of wavelengths per fiber could increase to more than 1000, and this clearly is not a limit [3]. A research has showed that one thousand wavelengths can enable forty million people continued connected with each other via voice, data or video, this finding is quite attractive and we can image that 100 fiber links could allow the word connect with each other. Though DWDM optical network can afford extremely high bandwidth, but it has a shortcoming: low spectrum utilization ratio. In traditional DWDM optical network the centre frequency of the spectrums are fixed on standard ITU-T (International Telecommunication Union Telecommunication Standardization Sector) grids 25GHz, 50GHz, 100GHz and 200GHz. If the client traffic volume cannot occupy the entire capacity of the frequency, the spectrum resource is wasted. In order to solve this problem the SLICE is proposed. In SLICE a whole spectrum is sliced into a lot of small spectrum slots. The slice process doesn't need to obey the ITU-T wavelength grids and spacing. The sliced spectrum slots are gridless which allows assigning spectrum resources in a gridless fashion [8]. SLICE is more flexible than DWDM, the spectrum utilization is much higher than DWDM network [9]. However the SLICE technology needs efficient resource allocation algorithm to manage the slots assignment process. As in this kind of optical network, the optical switch is used for traffic routing and a pair end users communicate with one another via all-optical channels, which are referred to as light paths [3], and a light path may span a range of fiber links. Which requires a light path must occupy the same spectrum slots on all the fiber links that it traversed, this property is called as the wavelength-consistency constraint. In SLICE, a single light path sometimes may require employ two or more spectrum slots depends on its traffic volume. If a light path requires n (n>=2) spectrum slots, if slot j is assigned to this light path with lowest index in the spectrum resource pool, then the slots j+1, … , j+n-1 should also be assigned to this light path. This is the so called wavelength-continuity constraint.

3 MNCASS DETAILS

In this paper, we assume that the route for each source destination pair is pre-selected. The problem we addressed on is static optical route establishment (SORE) problem. According to paper [10], for SORE problem the source and destination pairs are generated dynamically and the light path for them is pre-selected. The objective is for a given number of spectrum slots to establish as many as light paths, which can be quantized by blocking probability. The blocking probability is defined as: in a SLICE network, for a given set of connection requests N, try to assign spectrum slots for each of these connection requests. The total number of failed assigning connection requests is n and the blocking probability is defined as n/N. Under the spectrum slot continuity and consistency constraint, the SORE problem can be formulated as an integer linear program (ILP) [4]. Parameters are defined as follows:

1. K: Number of given network topology's source destination pairs.
2. L: Number of given networks' fiber links.
3. S: Number of spectrum slots per link.
4. $s_{ij} = \{0,1\}$, $s_{ij} = 1$, if the spectrum slots j on fiber link i is not assigned, else $s_{ij} = 0$.
5. $n = \{n_i\}$, $i = 1, 2,..., K$: The number of established light paths for the source destination pair *i*.
6. ρ: Provided load (the total amount of traffic demands).
7. $f = \{f_i\}$, $i = 1, 2,..., K$: Load fraction of the source destination pair *i* where $f_i.\rho$ is the established light paths for the source destination pair *i*.
8. *P:* Number of paths of a given network topology.
9. $H = (h_{ij})$: $P \times K$ source destination pair assignment matrix, $h_{ij} = 1$ if path i traverse the source destination pair *j*, otherwise $h_{ij} = 0$.
10. $V = (v_{ij})$: $P \times L$ fiber link assignment matrix, $v_{ij} = 1$ if path i includes the fiber link j, otherwise $v_{ij} = 0$.
11. $Z = (z_{ij})$: $P \times S$ spectrum slots assignment matrix, $z_{ij} = 1$ if wavelength j is assigned to path *i*, otherwise $z_{ij} = 0$.

We use the value of *Z0(ρ,f)* to represent the total number of established connections, the ILP problem's objective is to maximize this value, followed is the ILP formulation:

$$\text{Maximize: } Z_0(\rho, f) = \sum_{i=1}^{K_{sd}} n_i \qquad (1)$$

$$n_i \geq 0, \text{ integer}, i = 1,2,...,K \qquad (2)$$

$$z_{ij} \in \{0, 1\}\ i = 1,2,..., P, j = 1,2,...,S \qquad (3)$$

$$Z^T V \leq 1_{S \times L} \qquad (4)$$

$$n \leq 1_S Z^T H \qquad (5)$$

$$n_i \leq f_i \rho, i = 1,2,...,K \qquad (6)$$

Equation (1) is the objective function which represents the established light paths of the network. Formula (3) indicates that a spectrum slot can be used for one light path at the same time on a given link. 1S×L represents an S×L unity matrix. Formulas (5) and (6) indicate that the number of requested connections is no less than established connections, where 1S represents a 1×S unity matrix. Two ways can be used to decrease the blocking probability, one is using more spectrum slots, and the other is designing efficient resource allocation method to optimize the allocation procedure. In practical application, spectrum resources are constrained, algorithms needed during the assignment procedure. Constrained by above equations, we find that the lacking of contiguous spectrum slots is a significant cause of blocking probability increase problem.

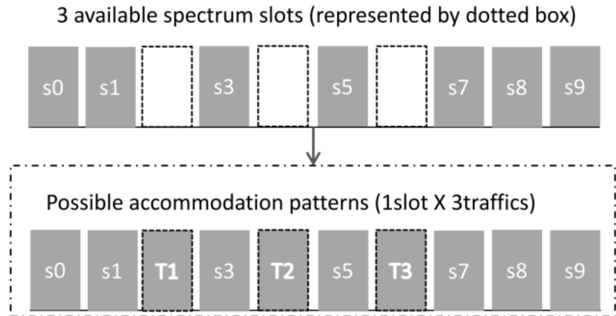

Fig.1. Three discrete one-slot segment

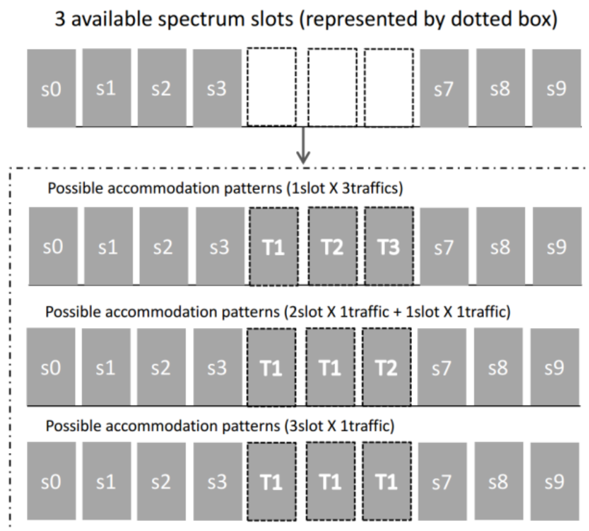

Fig.2 Single segment of three consecutive slots

he two situations represented in fig. 1 and fig. 2 both has the 3 available spectrum slots. However, as illustrated, fig. 2 can provide four different patterns of traffic demands but fig. 1 can only provide one pattern. It's clearly to see that situation 2 could provide a lower blocking probability. This is the key idea when we design the slots assign algorithm. We introduce Contiguous Available Spectrum Segments Value to model this problem. Contiguous Available Spectrum Segments Value is defined as follows: for a given link, the contiguous available spectrum segments value is the number of available spectrum segments, this value is not the number of spectrum slots. For a fiber if there are no light paths traverse it, the contiguous spectrum segments value is 1. We define a parameter r_j to represent the number of available continuous spectrum segments on fiber j, $r_j >= 0$. In fig. 1 this value equals to 3 and in fig. 2 it equals to1.

$$R_i = \sum_{j=1}^{L} v_{ij} . r_j \qquad (7)$$

Equation 7 represents the contiguous segment value of the light path i. A light path may traverse a set of links. Equation 7 means that the contiguous segment value of a light path equals to the sum of the contiguous available segment values of the links that the light path traversed. The objective of MNACSS is: after assigned the required resources to a connection request, keep all the traversed links' rest available slots have the smallest R_i. First the algorithm numbers the spectrum slots and generates a spectrum usage vector. When a connection request arrives, it search the traversed links' spectrum usage vectors from the little end to the big end, if all the traversed links have the required resources, the algorithm will call the evaluate function to calculate the light path contiguous segment value R1. Then it search the spectrum usage vectors from the big end to the little end and call the evaluate function to calculate light path contiguous segment value R2. Finally it compares the value of R1 and R2 and then choice the method with smaller R. Algorithm details is descripted as follows:

TABLE1

MNACSS algorithm	
1.	Number spectrum slots, generate spectrum usage vector.
2.	For each source destination pair, search the route from the route list, generate the traversed nodes sequence and get the required bandwidth.
3.	Search the spectrum usage vectors from big end to little end, if exist required number of contiguous slots, store these slots sequence number into matrix A1, change these slots status to used, evaluate the continuous value R_1 and change the used slots status to unused. Else block the request and go to step 7.
4.	Search the spectrum usage vectors from little end to the big end. Change the elected slots status to used, store these slots sequence number into matrix A2, evaluate the continuous value R_2 and change the used slots status to unused.
5.	If $R_1 < R_2$, Use slots in matrix A1 to establish the connection, go to step7.
6.	Else Use slots in matrix A2 to establish the connection.
7.	End

4 SIMULATION RESULTS

4.1 Simulation Assumptions

When building the simulation model to simulate both the FF algorithm and the MNACSS algorithm, we use following assumptions:

1. The route is pre-selected for each source destination pair. The routes are selected by the DIJK's algorithm.
2. There is one (bi-directional) fiber pair for each physical link. Path demand is bi-directional [5].
3. The network state is stable, so there is no path tears down.
4. Client requests' required bandwidths volume are represented by the number of slots. For the simulation model, the demand bandwidths are uniformly distributed between 3 and 12.
5. Each connection request arrives sequentially and we formulate the arrival are Poisson process. Thus the time between each pair of consecutive events has an exponential distribution with parameter λ and each of these inter-arrival times is assumed to be independent of other inter-arrival times [6].
6. The connection requests' hold time is an exponentially distribution with a normalized mean of one unit, thus the load is expressed in units of Erlangs [7].

4.2 Network Topology

We use the widely used 14-node NSF network (Fig. 3) structure and the 6-node mesh network (Fig. 4) during the simulation comparison process.

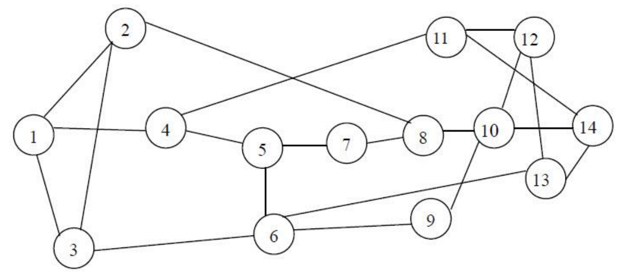

Fig.3 14-node NSF network

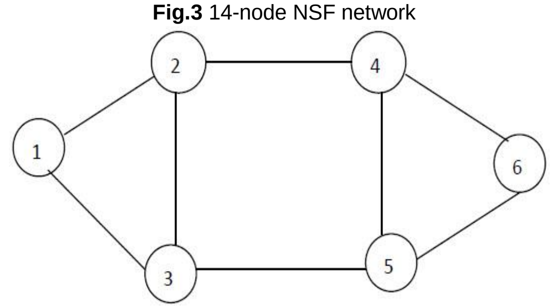

Fig.4 6 node mesh network

4.3 Comparison results

First we assume that each fiber link has 40 available spectrum slots and these slots are numbered from 0 to 39. The traffic load set of the network is E = {4, 8, 10, 12, 16, 18, 20}. We compare the blocking rate of MNACSS and First Fit methods using these values. Fig. 5 and Fig. 6 show the blocking probability in terms of traffic load under different network structures. It can be found that MNACSS algorithm's blocking probability is lower than the FF algorithm epically using the 14-node NSF network topology. Then we fix the traffic load, and set it to 28 Erlang, to see the blocking probability comparing results under different number of spectrum slots per fiber, the value set equals to {30, 35, 40, 45, 50, 55}. Fig. 7 shows that MNACSS is always better than FF even if the number of spectrum slots per fiber is small.

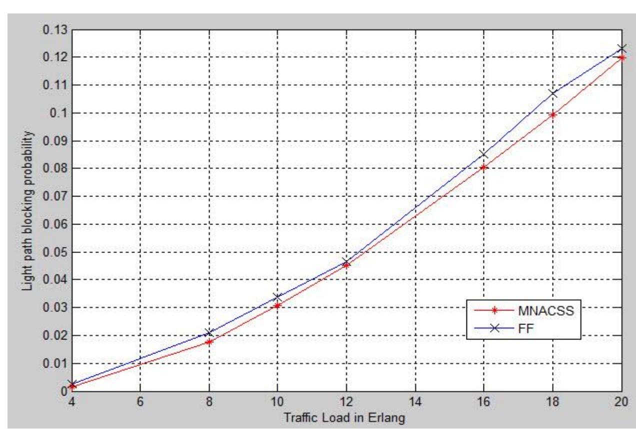

Fig.5 Blocking probability of MNACSS and FF under 6-node mesh network structure.

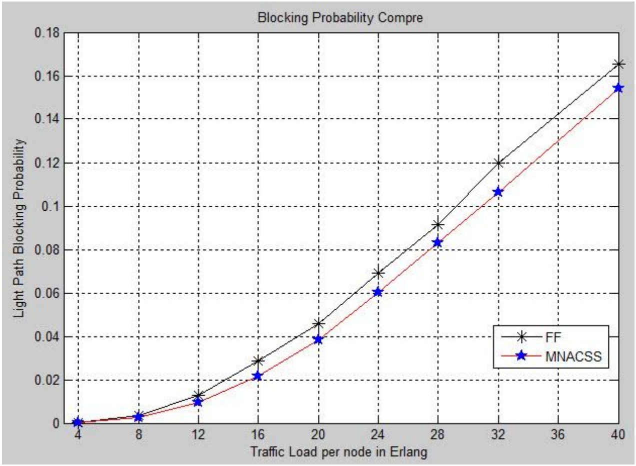

Fig.6 Blocking probability of MNACSS and FF under 14-node NSF network structure.

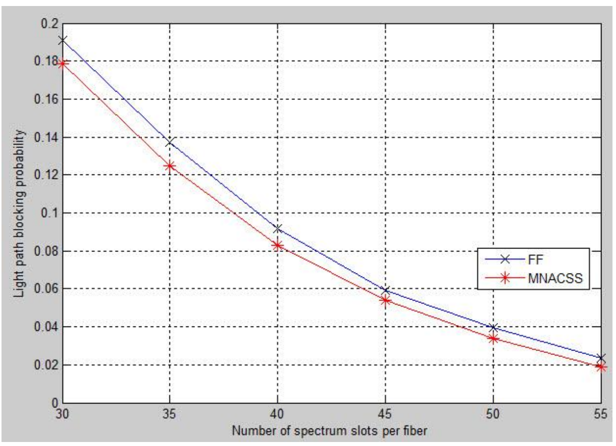

Fig.7 Blocking probabilities under different values of spectrum slots per fiber.

5 Conclusion

In this paper we proposed the spectrum resource allocation algorithm MNACSS and built a simulation model to simulate its performance. The simulation results show that MNACSS has a lower probability when compared with FF algorithm. Future works will be addressed on implementing MNACSS to a dynamic route selection scenario, it can be predicated that MNACSS would works much better than the static route scenario. Statistic methods should be used to improve the performance of MNACSS algorithm.

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