

# Development of New Algorithm for RWA Problem Solution on an Optical Multi-Networks

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## Abstract

This paper considers the problem of routing connections in a optical multi tree networks using WDM (Wavelength Division Multiplexing), where each connection between a pair of nodes in the network is assigned a path through the network and a wavelength on that path, so that connections whose paths share a common link in the network are assigned different wavelengths. The problem of optimal coloring of the paths on the optical multi-networks is NP-hard[1], but if that is the coloring of all paths, then there exists efficient polynomial time algorithm. In this paper, using a "divide & conquer" method, we give efficient algorithm to assign wavelengths to all the paths of a tree network based on the theory of [7]. Here, our time complexity is  $O(n^4 \log n)$ .

**Key Words :** optical multi tree network, WDM (Wavelength Division Multiplexing).

## 1. Introduction

Optical technology plays a practical part in today's communication networks and a central role in LAN and WAN[2]. With this technology, an optical wave can support a great transmission rate of several gigabytes per second and serve multiple channels of sound, data and video.

Even better transmission rates are provided when several laser beams are used, spreading abroad through the same optical fiber links from different light wavelengths. This remarkable technology is thanks to the WDM (Wavelength Division Multiplexing) method of dividing optical bandwidths into several channels and transmitting data streams simultaneously through the different channels within the identical links.

At present, the representative network techniques are increasing the number of wavelengths to expand line bandwidths and routing wavelengths to increase node capacity and heighten wave efficiency. But the number of wavelengths has limits and the minimum is required to economize network construction cost and meet telecommunication needs. Therefore, RWA (Routing & Wavelength Assignment) has to be first solved for an optimum WDM network.

In this paper, a tree-type network is presupposed. In fact, the tree type is the standard in the current telecommunications[5]. Also, the number of problems can be reduced by half when the paths of node pairs are assigned. In particular, even though there are some heuristic algorithm models as far as RWA is concerned, most problems in symmetrical tree networks are NP-hard[6][7].

The symmetrical tree networks are the network topology of the two opposite links. Here, dipaths passing through an edge in the same direction should use different coloring. That is, in [7] where the problem of RWA is that of coloring, the

minimum number of coloring is equal to the maximum number of wavelengths.

**[Theorem 1]**  $T$  is the given tree and  $S$  is the set of  $T$ 's dipaths. If  $c(T)$  is the minimum number of coloring(or wavelengths) to color  $S$ , and if  $I(T)$  is the maximum number of dipaths to go through an edge in  $T$ ,  $c(T) = I(T)$ .

However, [7] has only been defined and proved up to now. There is no paper yet concerning its actual algorithm. So, this paper aims to suggest new efficient polynomial time algorithm for all possible paths, based on [7].

## II. RWA Algorithm

The algorithm in this research is applied to all the paths in a common tree as given in Theorem 1. Wavelengths can be allotted based on  $c(T)$  or  $I(T)$ . As these two values are identical, either one will do for our work here.

Let's find the value of  $I(T)$ . It is the maximum number of paths among  $T$ 's edges. In general, the amount of paths can be revealed by multiplying the total nodes in two subtrees of a given tree  $T$ . Then, this problem can be solved by examining the maximal number of nodes.

If a node in a given tree  $T$  is  $v$ , and if the node  $v$ 's extra weight is  $w(v)$ ,  $w(v)$  is the total integral number of the subnodes including the node  $v$  itself. If the set of random nodes in the tree  $T$  is  $V$ , the following can be resulted:

$$w(V) = \sum_{v \in V} w(v) \quad (1)$$

For example,  $w(T)$  is the sum of all nodes in  $T$ . When a certain edge  $e$  is removed from  $T$ , two subtrees  $T_1$  and  $T_2$

are born. Here, the number of paths from  $T_1$ 's nodes to  $T_2$ 's nodes is  $w(T_1)*w(T_2)$ . Then,  $\Pi(T)$  is the maximum among the values of  $w(T_1)*w(T_2)$  against all edges. It is the maximum number of dipaths going through an edge in the same direction, while  $c(T)$  is the minimum number of coloring or wavelengths to color  $S$ , the set of dipaths.

However, we need the process of rearranging  $T$ . As seen in Fig. 1,  $p$  (the mother node of node  $i$ ) and all the above nodes are transformed into the tree of  $i$ 's son nodes and subnodes.

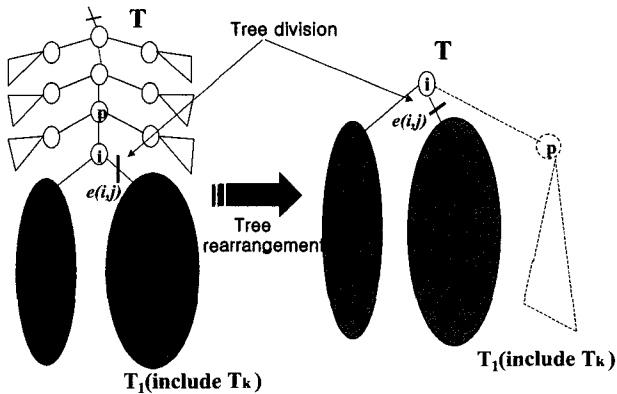


Fig. 1. Process of and rearranging for tree.

Therefore, there are two color assignment methods to all the paths of a given tree  $T$ :

- ① Global coloring: Wavelength assignment in a certain order within the range of  $\Pi(T)$  as to original subtrees  $T_1$  and  $T_2$ .
- ② Local coloring: Wavelength assignment in a certain rule within the range of  $\Pi(T)$  as to subdivided trees  $T_1$  and  $T_2$  while meeting the following restriction.

**[Restriction]** Any two paths sharing an edge in the same direction in a given network cannot be assigned the same wavelength.

**1) Global Coloring**

Wavelengths are assigned as follows:

- (1) Assignment from  $T_2$ 's all nodes to those of  $T_1$ 
  - ① DFS (Depth First Search) is kept from  $T_2$ 's root node to all nodes of  $T_1$ , assigning in the order of Color 1, Color 2, Color 3, .... Color  $w(T_1)$ . As extra weight,  $w(T_1)$  here is the number of  $T_1$ 's all nodes.
  - ② DFS is followed again from  $T_2$ 's next node to all nodes of  $T_1$ , assigning in the order of next color.
  - ③ This process is continued up to the final node of  $T_2$ , assigning as many as  $\Pi(T)$ .
- (2) Assignment from  $T_1$ 's all nodes to those of  $T_2$ .

The orders reverse to the above are kept. Namely, wavelengths are assigned from  $\Pi(T)$  down to Color 1.

**2) Local Coloring**

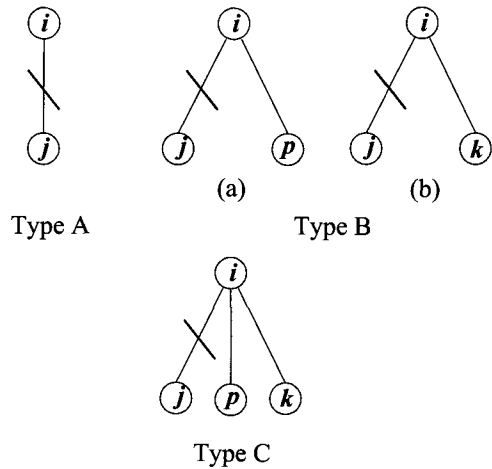


Fig. 2. Three types of tree.

After the initial global coloring, local coloring is done as to subtrees  $T_1$  and  $T_2$ . Here, the two subtrees are named  $T$ , and coloring is held among all the nodes of the two subtrees centered on a certain edge  $e(i, j)$ . As shown in Fig. 2, three types can be divided into three according to the number of node  $i$ 's son node number:

- Type A: When node  $i$ 's son node is 1, including node  $j$  (node  $i$ 's son node: node  $j$ )
- Type B: When node  $i$ 's son nodes are 2, including node  $j$  (node  $i$ 's son nodes: nodes  $j$  and  $k$  or  $j$  and  $p$ )
- Type C: When node  $i$ 's son nodes are 3, including node  $j$  (node  $i$ 's son nodes: nodes  $j$ ,  $k$ , and  $p$ )

In addition, according to the existence of node  $p$  (node  $i$ 's parent node), subtypes are divided. Color assignment is made:  $w(i)*w(j)$ . Here,  $w(i)$  is  $T_1$ 's root node and the number of  $T_1$ 's all nodes, while  $w(j)$  is  $T_2$ 's root node and the number of  $T_2$ 's all nodes.

The actual algorithm can be described as follows:

**Stage 1:** Extra weight

$w(1), w(2), w(3), \dots, w(v)$  (Here,  $w(v)$  is a random node in the tree  $T$ .) are found to know the edge  $e(i, j)$  with maximum paths.

**Stage 2:** Centered on this edge, the given tree  $T$  is rearranged with the node with the larger extra weight as the root node.

**Stage 3:** Centered on the particular edge  $e(i, j)$  found in Stage 1,  $T$  is subdivided into  $T_1$  and  $T_2$ .

**Stage 4:** Global coloring is applied when  $T$ 's all paths have no color. Otherwise, local coloring is held towards  $T_1$  and  $T_2$ .

**Stage 5:** With the given subtrees  $T_1$  and  $T_2$  as  $T$ , all the processes from Stage 1 to Stage 5 are repeated until  $T$  is not divided.

When the number of nodes in a given tree is  $n$ , time

complexity in Stage 1 is  $O(n)$  as each node is visited in the order of DFS. In Stages 2 and 3, it is  $O(e)$  as one visit to  $e$  is enough.

The case is quite different in Stages 4 and 5, because practical wavelengths are assigned to all the paths in the tree. For global coloring, one performance is enough. So time complexity is  $O(n^2)$ .

For local coloring, it's a bit complex. Local coloring of  $2^k (2 \leq k \leq \log n)$  is given per depth of  $\log n$ . The number of colors for each local coloring is  $n^2 (= n/2 * n/2)$ . Then, as to the search time of  $\log n$  to all the trees of  $(n/2^k * n/2^k)$ , performance of  $O(n^4 \log n)$  is achieved. This can be simply expressed as follows:

$$\sum_{k=2}^{\log n} 2^k \left( \frac{n}{2^{k-1}} + \frac{1}{2^{2k-1}} (n^4 \log n) \right) \leq n^4 \log n \quad (2)$$

So, the present polynomial time algorithm in this paper has time complexity of  $O(n^4 \log n)$ , efficiently assigning wavelengths to all the paths in a given tree.

### III. Conclusion

Optical multi-network technology is most significant in consideration of the upcoming superspeed information society. In particular, in terms of software, one of the urgent tasks in the environment of optical multi-networks is efficient assignment of wavelengths through the minimum number of wavelengths.

At present, most networks are simply composed of tree types. This paper covers the development of efficient polynomial time algorithm as far as RWA (Routing & Wavelength Assignment), or the matter of assigning wavelengths to all the given paths, goes.

The time complexity of the algorithm here is computed as  $O(S \cdot V)$ . This polynomial time algorithm needs to be improved. Task 1 in future is, therefore, how to improve total performance time by reducing the present time complexity. Task 2 is how to achieve more efficient wavelength assignment when partial link errors take place in the demanded tree or when additional connection is required after wavelength assignment to all the paths.

### References

- [1] T. Erlebach and K. Jansen. "Scheduling of Virtual Connections in Fast Networks", Proc. of 4th Workshop on Parallel Systems and Algorithms PASA '96, 1996.
- [2] P. E. Green. Fiber-Optic Communication Networks, Prentice-Hall, 1992.
- [3] A. Aggarwal, A. Bar-Noy, D. Coppersmith, R. Ramaswami, B. Schieber, M. Sudan. "Efficient Routing and Scheduling Algorithms for Optical Networks", in Proceedings of the 5th Annual ACM-SIAM Symposium on Discrete Algorithms(SODA'94), 1994.

- [4] J-C. Bermond, L. Gargano, S. Perennes, A. Rescigno and U. Vaccaro. "Efficient Collective Communications in Optical Networks", Proc. 23rd ICALP'96, Paderborn, Germany, 1996.
- [5] M. Mihail, C. Kaklamanis, S. Rao, "Efficient Access to Optical Bandwidth", Proceedings of 36th Annual IEEE Symposium on Foundations of Computer Science (FOCS'95), 1995.
- [6] Dhritiman Banerjee and Biswanath Mukherjee, Member, IEEE, "A Practical Approach for Routing and Wavelength Assignment in Large Wavelength Assignment in Large Wavelength-Routed Optical Networks", IEEE Journal on selected areas in communications, Vol. 14, No. 5, June 1996.
- [7] Luisa Gargano, Pavol Hell and Stephane Perennes, "Colouring Paths in Directed Symmetric Trees with Applications to WDM Routing", ICALP97, 1997.



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