An Online Wavelength Assignment Algorithm for Optical Network

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Abstract: We propose a dynamic wavelength assignment algorithm for online RWA problem in WDM networks with wavelength conversion. With our algorithm, for a given network condition, the following results have been proven mathematically: (1) the probability to find the set of wavelengths for a requested connection is equal or better than any other previously proposed algorithms, (2) our algorithm minimizes the usage of converters by chaining the minimum number of the longest wavelength continuous segments, leaving more converters available for future requests and (3) the complexity of our algorithm is reasonable, which is also another advantage of our algorithm.

Keywords: WDM, RWA, lightpath.

1. INTRODUCTION

The two most important problems of designing wavelength-routing network are lightpath topology design (LTD) and routing and wavelength assignment (RWA). LTD is the task to design a lightpath topology interconnecting the IP routers and to realize this topology within the optical layer. RWA is the problem of realizing the lightpath topology within the optical layer [1] . There are two kinds of RWA problems: offline problem and online problem. Offline problem is the solution of RWA determining the specific set of wavelength on each link to realize the specific lightpath topology. On the other hand, online problem has to be solved for one lightpath connection at a time [1] . For simplicity, RWA is divided into routing sub-problem and wavelength assignment sub-problem[1]. In this paper, we deal with the second sub-problem on the online model: assuming that the routes are fixed, and based on the local link state which has been collected by using [13], we focus on how to assign wavelengths for the source-destination pairs

A number of wavelength assignment algorithms have been proposed before: most-used (MU) [2], least-used (LU) [2], First-Fit (FF) [2], [4-6], [12], random algorithm [5][6][8-12][19] and wavelength-graph-based (WG) algorithm in [7]. Among them, FF has better blocking performance than the others, but MU. MU gives slightly better blocking performance than FF however, it requires global information [9] and has higher algorithm complexity.

In this paper, we propose a dynamic wavelength assignment algorithm based on the online model. When a connection is requested, the algorithm find the selection of consecutive links which have the same available wavelengths. With this algorithm, the following mathematical results has been proven for a given connection at a certain network condition 1) Our algorithm achieves much better blocking performance than other algorithms 2) the usage of wavelength converters is minimized, and 3) the algorithm complexity is $O(wkN)$ where w is the number of wavelengths per link (assume that the capacities of all links are the same); k is the number nodes from the source to destination nodes which have converter(s); and N is the number of intermediate nodes between the source node and the destination node. It should be noted that in most previous algorithms, the usage of converters has not been evaluated. Especially, no author shows that the usage of converters in his algorithm is minimum.

The rest of the paper is organized as follows. In Section 2, we define some definitions and present our algorithm. The mathematical results are presented in Section 3. Finally, section 4concludes this paper

2. PROPOSED WAVELENGTH ASSIGNMENT ALGORITHM

It is clear that the wavelength converters can significantly reduce the blocking probability of the networks. However, their price is still so high. Hence, wavelength converters are considered as one of the critical network resources. Therefore, the problem is how to minimize the usage of wavelength converters but also improve the blocking probability. Our algorithm solves these issues.

In this paper, it is assumed that the route is selected for a given source-destination pair. The remaining work is only how to assign wavelengths along the route from the source node to the destination node.

Suppose that for a given source-destination pair, we have the route to connect the source node and the destination node as in Fig. 1.

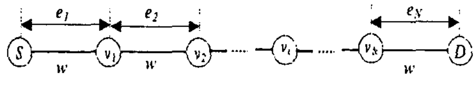

Fig 1. A route for a given connection

In Fig. 1, S and D indicate the source node and destination node respectively; $v_1, v_2, \ldots, v_N$ are the intermediate nodes from the source to the destination; $e_1, e_2, \ldots e_N$ are the links connecting S and v_1, v_1 and v_2, ..., v_N and D respectively. Note that $v_1, v_1, \ldots v_N$ can be the source and/or destination nodes of other connections, however, in this case we do not consider them as either source or destination node. In addition, w denotes the capacity of each links (assume that the capacities of all links are the same), so we have w wavelengths in each link: $\lambda_1, \lambda_2, \ldots, \lambda_w$.

For each connection on the route from the source to the destination, a segment is defined as:

1) the chain of the largest number of the consecutive links which have the same particular wavelength available.
2) the direction of the segment advances toward destination node.
3) the starting node of the segment is the source node of that connection or a converter and the ending node of the segment is the destination of that connection or before using another converter, and
4) nodes in the segments must be the ones on the route.

Our algorithm deals with online wavelength assignment problem. When each connection arrives, from the source node, we consequently find all segments for each free wavelength and among them, select the one which has longest length until the destination is reached.

The following is the detail of our proposed algorithm:

Step 0:

- i = 0;
- Starting node of segment 0 = source node

Step 1:

- From the starting node of segment i, find all candidate segments for segment i.
- Segment i is selected as the longest one among those candidate segments.

Step 2:

- If (the ending node of segment i = destination node) Then
  Stop.
- Else
  - Starting node of segment (i+1) = the ending node of segment i.
  - i=i+1.
  - Go back to step 1

In the next sections, we present some mathematical results of Longest Segment Algorithm. As we will see, our algorithm outperforms previously proposed algorithms in terms of blocking probability and converter usage.

3. MATHEMATICAL RESULTS

As an example to demonstrate the power-constrained This part demonstrates some mathematical results and their proof. Again, one should recall that, in this work, we assume that the route for a given connection is obtained by some given routing algorithm.

With a chosen route for a source-destination pair, suppose that there is at least one wavelength assignment approach to form a lightpath from the source to the destination. Then, the following theorems have been proved under this assumption. Most of the proofs use the contradiction method in mathematics.

Theorem 1: The solution for our algorithm is always found.

Proof: Assume that the solution for algorithm does not exist. That means at the ending node of a given segment, we cannot go to the ending node of another segment in the direction toward the destination node.

Let v_j be the ending node of that given segment and v_t ($j < t \leq N$) be the closest node to v_j which has converter. If that node does not exist, so v_t is the destination node. We will show that the consecutive links starting from link e_{j+1} (starting at node v_j) to link e_t (ending at node v_t) form a segment.

Fig 2. Consecutive links from node v_j to v_t

Because there is at least one way from the source to the destination, the link e_{j+1} (between nodes v_j and v_{j+1}) must have one or more available wavelengths. Then, the link e_{j+2} must have the same free available wavelength(s) with link e_{j+1}. If not, we cannot go from v_j to v_{j+2} and hence, we cannot go to the destination node. This conflicts with the statement that there exists at least one possible lightpath from the source node to the destination node. Similarly, the link e_{j+3} must have the same available wavelength with link e_j (in case $j+3 \leq t$) until links e_t is reached.

However, according to above assessment that we cannot go to the ending node of another segment in the direction toward the destination node, then from e_j we cannot go to e_t because e_t is the ending node of the segment from e_j to e_t. This is a contradiction, that is the assumption that the solution for our proposed algorithm does not exist is incorrect. Hence, the theorem 2 is proved.

Theorem 2: The number of converters used is minimized.

Proof: Suppose another wavelength assignment algorithm employs less number of converters.

Suppose that the number of converters used in our algorithm is n, and the nodes which have converters to be used are $v_{i_1}, v_{i_2}, ..., v_{i_n}$. Also, let the number of converters used in another wavelength assignment algorithm which employs less the number of converters be m, at the locations $v_{j_1}, v_{j_2}, ..., v_{j_n}$. Obviously $n>m$. Note that the consecutive links from source to v_{i_1} , from v_{i_1} to v_{i_2} , ..., and from v_{i_n} to the destination are segments defined as before.

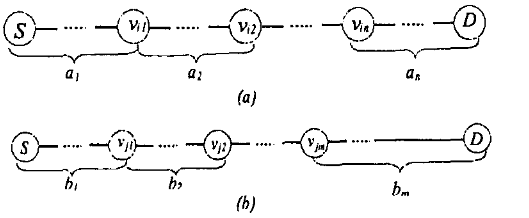

Fig 3. Locations of nodes which have converters used (a) in our algorithm and (b) in another algorithm.

In our algorithm, let:
a_1 (length unit) be the length from the source node to v_{i_1}.
a_2 (length unit) be the length from v_{i_1} to v_{i_2} , and a_n (length unit) be the length from v_{in} to the destination node.

In another algorithm, let:
b_1 (length unit) be the length from the source node to v_{j1}
b_2 (length unit) be the length from v_{j_1} to v_{j_2}
...
b_m (length unit) be the length from v_{j_m} to the destination node.
Because the lengths from the source node to the destination node in two algorithms are the same, we have:

$$a_1 + a_2 + ... + a_n = b_1 + b_2 + ... + b_m \qquad (1)$$

Due to the characteristics of selecting the longest segment, the segment from source to node v_{i_1} must be longer than the one from the source node to node v_{j_1} .
We have $a_1 \geq b_1$.
If $a_2 \geq b_2$, obviously we have $a_1 + a_2 \geq b_1 + b_2$.

Let A be the length between node v_{j_2} and v_{i_2} . In case $a_2 < b_2$ we will show that $i_2 \geq j_2$, then we still have $a_1 + a_2 \geq b_1 + b_2$ because $a_1 + a_2 = b_1 + b_2 + A$.

Indeed, if $i_2 < j_2$, then the length from i_1 to j_2 must be longer than the length form i_1 to i_2 because it includes the length from i_1 to i_2. Therefore, the segment starting from i_1 and ending at i_2 is shorter than the segment starting from i_1 and ending at j_2. This contradicts with the selection of our algorithm. So, we have $i_2 \geq j_2$ that means we always have $a_1 + a_2 \geq b_1 + b_2$. Similarly: $a_1 + a_2 + a_3 \geq b_1 + b_2 + b_3$ and so on. Finally:

$$a_1 + a_2 + ... + a_m \geq b_1 + b_2 + ... + b_m \qquad (2)$$

Besides, $a_1 + a_2 + ... + a_m + ... + a_n > a_1 + a_2 + ... + a_m$, hence we have:

$$a_1 + a_2 + ... + a_m + ... + a_n > a_1 + a_2 + ... + a_m \geq$$
$$\geq b_1 + b_2 + ... + b_m \qquad (3)$$

We see that (3) conflicts with (1), that means the assumption is not correct. We can conclude that the usage of converters in our algorithm is optimum.

Theorem 3: The algorithm complexity is equal or less than $O(wkN)$, where w is the capacity of each link, k is the number of nodes which have wavelength converters and N in the number of immediate nodes between the source node and the destination node as we defined before

Proof: Algorithm complexity is defined as the number of steps to complete that algorithm.

Consider the link e_1, the number of available wavelengths is no larger than w. In the worst case, the number of wavelengths is w.
Assume that with λ_1, we have segment 1 ending at node v_{i1}
With λ_2, we have segment 2 ending at node v_{i_2} .

...
With λ_w, we have segment w ending at node v_{i_w}

$v_{i_1}, v_{i_2}, ..., v_{i_n}$ may not exist if the respective wavelength is not available.

Let $x_1 = \max \{i_1, i_2, ..., i_w\}$ then the selected segment starting form the source node will end at node v_{x1}, and the number of steps for selecting the first segment is no larger than $w \cdot x_1$

Now consider the second segment, starting from node v_{x_1} .

Assume that with λ_1, we have segment ending at node $v_{x_1+j_1}$
With λ_2, we have segment 2 ending at node $v_{x_1+j_2}$

...
With λ_w, we have segment w ending at node $v_{x_1+j_w}$ $v_{x_1+j_1}$, $v_{x_1+j_2}$, ..., $v_{x_1+j_w}$ may not exist if the respective wavelength is not available.
Let $x_2 = \max \{x_1+j_1, x_1+j_2, ..., x_1+j_w\}$ then the second selected segment starting form node v_{x_1} will end at

node $v_{x_1+j_w}$ and the number of steps for selecting the second segment is no larger than $w \cdot x_2$

If there are N intermediate nodes from source node to the destination node, we have: $x_1+x_2 \leq N$.

Consider the third segment:

Assume that with λ_1, we have segment ending at node $v_{x_2+t_1}$.

With λ_2, we have segment 2 ending at node $v_{x_2+t_2}$

...

With λ_w, we have segment w ending at node $v_{x_2+t_w}$

$v_{x_2+t_1}, v_{x_2+t_2} \ldots, v_{x_2+t_w}$ may not exist if the respective wavelength is not available.

Let $x_3 = \max\ \{x_2+t_1, x_2+t_2, \ldots, x_2+t_w\}$ then the third selected segment starting form node v_{x_2} will end at node v_{x2+tw} and the number of steps for selecting the second segment is no larger than $w \cdot x_3$

If there are N intermediate nodes from source node to the destination node, hence $x_1+x_2+x_3 \leq N$

Suppose we have k segments, then the number of steps is less than or equal to $w\times(x_1+x_2+\ldots+x_k)$

Let $S= x_1+x_2+\ldots+x_k$. We have

$x_1 \leq N$

$x_2 \leq N-x_1$

$x_3 \leq N-x_1-x_2$

...

$x_k \leq N-x_1-x_2-\ldots-x_{k-1}$

$\Rightarrow S = x_1+x_2+\ \ldots\ +x_k \leq (k-1)N-[(S-x_k)+(S-x_k-x_{k-1})+\ldots+(S-x_k-x_{k-1}\ldots-x_2)]$

$\Rightarrow S \leq (k-1)N-(k-1)S+[x_2+2x_3+\ldots+(k-1)x_k]$ or

$kS \leq (k-1)N+[x_2+2x_3+\ldots+(k-1)x_k]$

Because $x_j \leq N$ with $1 \leq j \leq k$ we have:

$$kS < (k-1)N + \left[1+2+\ldots+(k-1)\right]n$$

$$\Leftrightarrow kS < (k-1)N + \frac{k(k-1)}{2}N$$

$$\Leftrightarrow kS < N(k-1)\left(1+\frac{k}{2}\right)$$

$$\Leftrightarrow S < N\frac{(k-1)}{k}\left(1+\frac{k}{2}\right)$$

$$\Rightarrow S < N\left(1+\frac{k}{2}\right)$$

$$\Leftrightarrow wS < wN\left(1+\frac{k}{2}\right)$$

As a result, the number of steps to complete the wavelength assignment in our algorithm is no larger than $w \cdot S$.

$$\text{O(LS algorithm)} \leq O\left(wN\left(1+\frac{k}{2}\right)\right) = O(wNk) \qquad (4)$$

In case that k is small or constant, the algorithm complexity is $O(wN)$ which is comparable with MU and LU algorithms.

4. CONCLUSIONS

In this paper, we propose a dynamic wavelength assignment algorithm for all-optical networks. By connecting a minimum number of consecutive segments, our algorithm establishes an optical path with the least wavelength conversions, leaving more converters available for future requests. Mathematical result shows that blocking performance in our algorithm is much better than other algorithms for one connection with given network condition. Compared with MU algorithm, our algorithm has comparable complexity, lower blocking probability and uses less converter conversions. The minimal converter usage not only reduces the blocking probability but also minimizes the optical signal degradation induced by cascaded wavelength translations performed at routing nodes. The reasonable complexity and the requirement only for local information about wavelength allocations on links and converter availabilities on intermediate nodes on the route for a given source-destination pair are other advantages of our algorithm.

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