DYNAMIC WAVELENGTH ASSIGNMENT IN WDM NETWORKS WITH SPARSE WAVELENGTH CONVERSION

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ABSTRACT

In this paper, we consider the process of setting up a lightpath in WDM networks with sparse wavelength conversion. We propose a novel probe packet format for the destination initiated reservation (DIR) signalling scheme to be used with any routing function to collect route status information. In addition, we propose a wavelength assignment algorithm that minimizes the number of wavelength conversion used along the route.

1. INTRODUCTION

In wavelength-routed networks, wavelength converters can significantly reduce blocking probabilities by increasing the number of alternate routes. However, since wavelength converters are still very expensive and their associated performance improvement reduces as the number of converters increases, it is not practical to use a converter for every wavelength at every node. A more practical approach is to use *sparse wavelength conversion*, which refers to using wavelength converters at only a small number of nodes [1]. In such a network, it is desirable to minimize the number of converters used for current connections in order to decrease the probability of blocking a new connection due to a lack of converter. We shall focus on setting up a lightpath using the minimum number of converters.

Chlamtac [2] and Zhang [3] proposed a wavelength assignment (WA) scheme for a lightpath setup that finds all available wavelengths and selects the one using the minimum number of wavelength converters. Their approach is based on transforming the routes in the network into their corresponding *wavelength graph*s on which shortest path routing is applied. The drawback of this approach is the high computational complexity associated with the graph transformation.

Shen [4] proposed a heuristic WA algorithm without graph transformation. His approach is to select the available wavelength, if exists, with the smallest index. If such wavelength does not exist, the algorithm iteratively finds the first node (from source to destination) with an available wavelength converter and considers this node as the source node for the remaining portion of the lightpath. Even without graph transformation, running time may be long because of the repeated process of finding continuous available wavelengths on all downstream links. In addition, since the first encountered converter is always used, the resultant number of used converters tends to be high.

Recently, Ho [5] proposed the multi-hop-lambda assignment and re-assignment method with the definition of a *lambda run* as a wavelength-continuous group of consecutive links. A lambda run begins at the source node or a node with an available converter. Based on the observation that wavelength conversion is only needed when the lightpath transits from one lambda run to another, the algorithm first finds all lambda runs, sorts them according to their lengths, and then removes all redundant lambda runs whose removals do not break the connectivity of the route. The algorithm finally selects the wavelengths from the remaining lambda runs. Because the remaining lambda runs tend to be long, the number of converters used is small compared to previous works. However, Ho’s algorithm does not always find a solution even if one exists since the ending node of a lambda run may not have a converter available. In addition, the number of converters used by this algorithm is not necessarily the minimum. Finally, the computational complexity is still high because we need to find all possible lambda runs and remove all redundant ones.

In all WA algorithms mentioned above**,** we must obtain the information regarding wavelength availabilities on all links and converter availabilities at all nodes by sending a probe packet from the source to the destination. We observe that, due to the wavelength continuity constraint and lack of wavelength converters, some wavelengths cannot be used although they are available on some links. It is the redundant information about these wavelengths that complicates the WA process. In this paper, we propose a novel probing scheme that can detect and mark unusable wavelengths as the probe packet travels along the route. By marking the unusable wavelengths, we obtain a small number of candidate lambda runs for the lightpath setup. In addition, compared to previous works, we also reduce the size of the probe packet, resulting in the reduction of lightpath setup time. We also propose a simple WA algorithm that is proved to use the minimum number of wavelength converters on the setup lightpath. Finally, we show that our algorithm complexity is not higher than those in the previous works.

2. PROPOSED DYNAMIC WAVELENGTH ASSIGNMENT ALGORITHM BASE ON DIR SCHEME [6]

In this paper, we assume that the route for a lightpath setup was already selected by some routing algorithm and is denoted by $(s,v_{h-1},...v_2,v_1,d)$, with w wavelengths in a link, h-1 intermediate nodes of which k nodes have available wavelength converters.

2.1 Signalling scheme

Step 1: With a selected route, we send a probe packet from the source node (node s) to the destination node (node d). Each intermediate node v_i attaches information of the node itself and its incoming link. If there is no "usable" wavelength on its incoming link, node v_i responds to node s with a NACK packet indicating that there is no possible lightpath.

Step 2: When the probe packet arrives at node d, our wavelength assignment algorithm performed at node d selects a lightpath and sends a reservation (RES) packet back to node s.

Step 3: Upon arrival of the RES, node v_i reserves the selected wavelength and converter, and forwards the packet towards node s. If the selected wavelength or converter has been reserved by another request, node v_i sends a FAIL packet that will release all things that have been reserved to node d and a NACK packet to node s. When the RES arrives node s, one lightpath is setup.

2.2 Proposed a novel probe packet format to collect status route

Figure 1 shows the probe packet format.

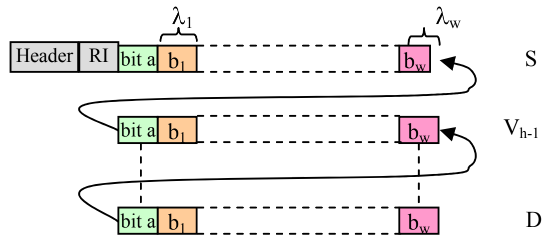

Fig1: Probe-packet Format

The packet Header contains Packet ID and Route ID

RI (Route Information) contains the names of nodes in the order $(s,v_{h-1},...v_2,v_1,d)$.

Next is data of the route that are added at each intermediate node. Bit a indicates the converter state at each node, bit b_1, b_2 ... b_w indicate the wavelength state in the incoming link of the each node. In particular, let $a^{(j)}$, $b_1^{(j)}$, …, $b_w^{(j)}$ denote the bit value at node j. Let $\lambda_1^{(j)}$, …, $\lambda_w^{(j)}$ denote the W wavelengths in each fiber on the outgoing link from node j (with j = h on the first link from node s). We set $a^{(j)}= 1$ if node v_j has at least one available converter, and set $a^{(j)}= 0$ ortherwise. In addition, we set $b_i^{(j)} = 1$ if both $\lambda_i^{(j)}$ and $\lambda_i^{(j+1)}$ are free , or if $\lambda_i^{(j)}$ is free and $a^{(j)} = 1$. Otherwise, we set $b_i^{(j)} = 0$. Note that $b_i^{(j)} = 1$ means $\lambda_i^{(j)}$ is "usable".

2.3 Proposed WA Algorithm

Definition of Segment: Consider a lightpath from node s to node d along the route $(s,v_{h-1},...v_2,v_1,d)$. A segment of this lightpath on λ_i beginning at node v^* is a maximum set of consecutive links starting from v^* towards node s and λ_i is "usable" on those links.

Description of the algorithm: The main idea of this algorithm is to find the longest segment starting from the destination node. The algorithm then iterates using the end node of the segment as the starting point for the next step. The algorithm terminates when the source node is reached. The following is the detail of the algorithm:

Initial: Let i = 1;

Step 1: From the starting node of segment i, find all candidate for segment i.

Step 2: Select the longest one called segment i (small wavelength index first)

Step 3: If the ending node of segment i is node s, then set the lightpath to be the sequence of segments found

Else i = i + 1 and go back to step 1.

3. MATHEMATICAL ANALYSIS

3.1 Our algorithm minimizes the usage of converters

Theorem 1: The ending node of the segment found in our algorithm is the node having an available converter or the source node.
Proof:

The number of segments in a route is m. (m must be finite and $m \geq 1$)

If m = 1, the ending node of the segment certainly must be the source node.

If m > 1: Consider the first segment. This segment begins with node d and ends with node V_k. For m > 1, V_k cannot be the node s. We will prove that at node V_k, there exists at least one available converter.

- Suppose that we have no available converter at node V_k
- Denote the wavelength in this segment by λ_i. We know that λ_i is in usable on link 1, 2 …and k, where the link index increases from node d to node s.
- From the properties of the segment, we know that on the k+1[th] link, λ_i is not usable. So, we get $b_i^{k+1} = 0$.
- Because at node k, if we don't have at least one available converter (as supposing above) and $b_i^{k+1} = 0$, we deduce $b_i^k = 0$, which means λ_i is not usable on the k[th] link. This contradicts with the above statement that λ_i is usable on link k. So there must exist at least one available converter at node V_k
- By a similar deduction, we can prove that the ending node of segment 2 also has at least one available converter. This is also true for segment 3, 4,… , m – 1.
- Consider segment m. For the route only has m segments, the ending node of segment m must be the source node. ☐

Theorem 2: If it is possible to set up a lightpath for a route, then the solution for our algorithm is always found.

Proof:
We are always able to define segment 1.Let's consider 2 cases below:

Case 1: If segment 1 ends with the source node, we have the solution for our algorithm.

Case 2: If segment 1 does not end with the source node, from theorem 1, it must end with a node that has at least one available converter.

- At the ending node of segment 1, say node v_k, we can always connect to segment 2 because we have at least one available converter at node v_k. Therefore, we can "transmit" from segment 2 to segment 1.
- With a finite number of nodes in the route, by a similar deduction we conclude that there always exists segment m of which the ending node is the source node. In addition, we are also able to "transmit" from segment m to segment m-1. Hence the solution is always found.

Theorem 3: When using our algorithm, the number of wavelength converters used in the route is the minimum.

Proof

Let n denote the number of wavelength converters used for a route in our algorithm and Vi_1, Vi_2,.. Vi_n denote the nodes whose converters are used in our algorithm. We shall refer this solution as solution 1.

Let m be the number of wavelength converters used in another algorithm and Vj_1, Vj_2,.. Vj_m denote the nodes whose converters are used. We shall refer this solution as solution 2.

We need to prove that $n \leq m$. Suppose that $m < n$.

From the properties of segment 1, we have $j_1 \leq i_1$

We now show that $j_2 \leq i_2$.
Suppose that $j_2 > i_2$. Then we get the scenario as illustrated in Fig. 2.

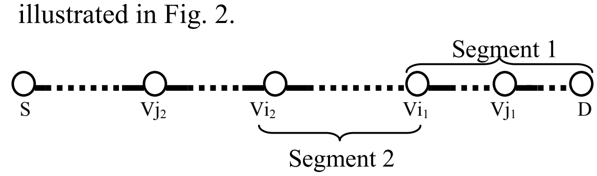

Fig 2: Relationship of locations of nodes using a wavelength converter in the case $j_2 > i_2$

Since $j_1 \leq i_1$ and $j_2 > i_2$, $[j_1, j_2] \supset [i_1, i_2]$ where [p,q] denotes the set of links from node p to node q.

Besides, solution 2 shows that there exists a continuously available λ_i from node j_1 to j_2. So λ_i is also continuously available from i_1 to j_2. This is in contrast with properties of segment 2 in solution 1. So, $j_2 > i_2$ is false. Hence, $j_2 \leq i_2$.

By the same argument, we deduce $j_m \leq i_m$.

Fig. 3 illustrates the wavelength converter locations for the two solutions

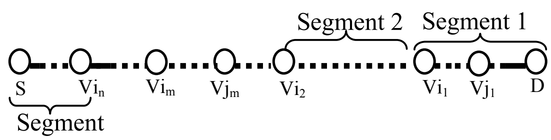

Fig 3: Relationship of locations of nodes using a wavelength converter in two solutions

Base on Fig. 3, in solution 1 we remark that there are more than one segment between node i_m and source node.

However, we know that there exists a continuously available wavelength, say λ^*, from node j_m to source node. Since $j_m \leq i_m$, λ^* is also continuously available in that section. So, from i_m and destination node, there is only one segment, which is contradictory to the above segment about multiple segments from i_m to s. Therefore, we deduce m < n is false. ☐

3.2 Complexity of our proposed WA algorithm.

Given a route $(s,v_{h-1},...v_2,v_1,d)$ that has k nodes with availabe converter capability nodes, in the worst case, k wavelength conversters is used, yielding k+1 segments. Let $Vi_1, Vi_2,\ldots,Vi_k$ be the nodes whose wavelength converters are used.

Segment 1 begins with node d and ends with node V_{i1}. In the worst case, the number of candidates of segment 1 is w (one segment corresponds with a wavelength). From node d to node V_{i1}, we have i_1 links. So we need maximum i_1 steps for each candidate and w step to select the longest one. So the maximum steps for segment 1 are $w.i_1 + w$.

Similarly, the maximum number of candidates of segment 2 is w and its link is $i_2 - i_1$. Hence the number of steps for selecting the second segment is $w(i_2 - i_1) + w$.

Therefore, the maximum number of steps for the overall lightpath setup process is $S = w\,(h - i_k + i_k - i_{k-1} + i_{k-1} - i_{k-2} + \ldots + i_2 - i_1 + i_1 + k) = w.(h + k) \leq 2wh$

Thus the complexity of our WA algorithm is O(wh) which is smaller than the complexity of $O(whlog_2(wh))$ for all preciously algorithms having the same objective [5].

4. CONCLUSION

We propose a novel probe packet format and a wavelength assignment algorithm to be used with the DIR signalling scheme. Our proposed WA algorithm is superior to previously proposed algorithms in two ways. First, the number of wavelength conversions in the lightpath is always the minimum. Second, the complexity of our algorithm is always less than previously proposed algorithms. In summary, our proposed algorithm makes the wavelength converter usage in an optical network more efficient.

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