Lightpath Affiliation Graph Approach for Wavelength Assignment of Lambda Leasing Service

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Abstract

In view of practical engineering and service deployment requirements, we propose to apply Lightpath Affiliation Graph partitioning heuristic for the wavelength assignment in mesh optical transport networks to support emerging lambda leasing service.

Introduction

Point-to-point or ring structure SONET/SDH technologies have been widely adopted by traditional network operators since its introduction in 90's last century to support a variety of transport services. It is known that ring based networks suffer from poor scalability problem, i.e., six to eight nodes per ring are deployed for metro transport in practice. On the other hand, enterprise customers are demanding more bandwidth to support applications such as inter-sites backup, and fixed/mobile carriers are looking for low cost interconnection services. Owing to the need of using optical-electrical-optical (OEO) signal conversion, SONET/SDH technologies are not cost effective when it is used to support emerging high data rate applications. Therefore, the lambda leasing service (wave service) [1] that offers end-to-end transparent wavelength channels (lightpaths) to connect customer sites directly is becoming important to network operators. Network operators are interested in mesh optical transport networks that can support transparent transmission services, promote architectural flexibility and save cost. Recently, the availability of reconfigurable optical add-drop multiplexer (ROADM) has brought in multi-degree (steering optical signals to three or more trunk fiber ports) optical switching capability to enable mesh topology optical networks [2]. To deliver lambda leasing service successfully, however, an efficient and handy desktop planning tool that can address engineering and service deployment requirements to facilitate complex wavelength assignment in mesh optical networks should be available for network planners.

The Lightpath Affiliation Graph Approach

Based on the experience of carrier class service deployment, a number of prevailing issues/criteria should be considered when we design the wavelength assignment tool. These issues/criteria include:

1. The data communication equipment (e.g. switches, routers, media converters) at the customer ends normally equips with Small Form-factor Pluggable (SFP) transceiver of only a few specific wavelengths to minimize SFP stock variety;
2. In general, edge ROADM does not come with the costly wavelength conversion capability. Therefore, two customer sites can interwork only if both SFPs operate on same wavelength channel;
3. ROADM internal elements such as the ingress port filter for conditioning the SFP output signals to precise wavelength grid should be minimized;
4. Higher tier customers require timely network management actions. The signal quality of these customers should be closely monitored;
5. The number of customer access links should be minimized in a multi-fiber network (MFN);
6. Commercial service is normally offered as cohort of readily available lightpaths.

For Criterion 2, wavelength assignment should comply with the wavelength continuity constraint (WCC) such that same wavelength channel should be assigned for all of the links in a lightpath. Also, we cannot assign the same wavelength to two lightpaths on the same link, i.e., wavelength exclusivity constraint (WEC). Apart from WCC and WEC, one can observe that we should assign the same set of wavelength channels, if possible, amongst the same customer or same tier of customers. It will reduce the equipment and operation costs when lambda leasing service is offered to customers. We define that a group of lightpaths are **compatible** if they can be assigned to the same wavelength. An **affiliated customer group** is the group of customers having lightpaths of same set of wavelengths. An **affiliated lightpath group** is the largest group of compatible lightpaths assigned to the customers in an affiliated customer group. Hence, the wavelength assignment problem of lambda leasing service can then be turned into the problem of searching the appropriate affiliated lightpath groups.

From an affiliated ligthpath group, we observe that the wavelength assignment problem is equivalent to the clique partitioning problem if we treat lightpaths as clique members. Clique is an affiliated group of compatible entities. The clique concept has been widely studied in research areas such as human behavior and graph theory. Although the general clique partitioning is also an NP-completed problem, a large number of mathematical tools are available to solve clique partitioning problems. Owing to the lightpath grouping nature of lambda leasing service, clique partitioning is

978-1-4244-4103-7/09/$25.0 © 2009 IEEE

more appropriate for network planning than general wavelength assignment methods [3,4].

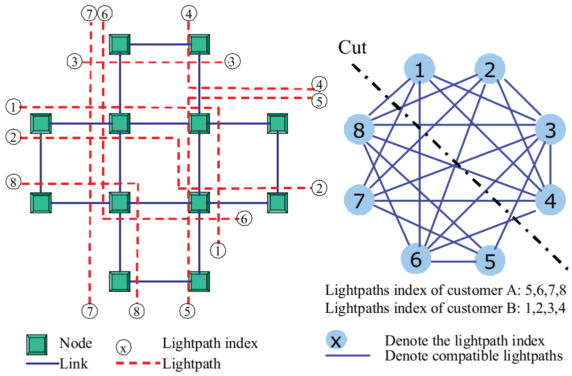

Fig. 1. (a) Eight-lightpaths network (b) LAG with graph "cut"

Using the eight-lightpath mesh network shown in Fig. 1(a) as an example, we demonstrate how clique partitioning can be used to solve the wavelength assignment problem of lambda leasing service. According to the WCC and WEC, we first draw a compatible graph for the ligthpaths in Fig. 1(b). Each lightpath i is denoted by a vertex v_i. The compatibility relationship is denoted by an edge e_{ij}. There will be no edge e_{ij} if lightpaths i and j (v_i and v_j in Fig. 1(b)) share a common fiber link. This graph is called the basic *Lightpath Affiliation Graph* **LAG (V,E)** in lambda leasing service application. For customer B, a maximum complete sub-graph such as (v_2-v_3-v_4) in Fig. 1(b) is a maximum clique representing one of possible affiliated lightpath group. In principle, we should select and partition the cliques based on affiliated customer groups. For demonstration purpose, however, we use a linear time iteration method [5] for clique partitioning and treat customers A and B as the same affiliated customer group. We select and delete the maximum clique in LAG at each round of iteration until the LAG becomes empty. For each maximum clique extraction, a wavelength is assigned to the associated lightpaths of maximum clique. The number of iterations will therefore equal to the number of wavelengths required.

Model	Size (node, edges)	Model	Size (nodes, edges)
1.RWA_10-0	10 nodes, 14 edges	6.RWA_15-2	15 nodes, 20 edges
2.RWA_10-1	10 nodes, 15 edges	7.RWA_20-0	20 nodes, 35 edges
3.RWA_10-2	10 nodes, 11 edges	8.RWA_20-1	20 nodes, 34 edges
4.RWA_15-0	15 nodes, 18 edges	9.RWA_20-2	20 nodes, 35 edges
5.RWA_15-1	15 nodes, 25 edges		

Table 1. Network models generated by GT-ITM

The proposed LAG heuristic has been verified with integer linear programming (ILP) wavelength assignment method using the random topology networks generated by Georgia Tech GT-ITM topology generator. Nine network topologies are shown in Table 1. Floyd-Warshall shortest path algorithm is used to locate physical paths between every pair of source s and destination d. Traffic equations satisfying all flow constraints are modeled as ILP equations to yield minimal number of wavelengths as objective. An Intel x86 3GHz computer installed with CPLEX [6] was used

	Integer Linear Programming (CPLEX)						LAG approach	
Topology Model	Variable	Constraint	Mps file size	Read time (s)	Sol. Time (s)	ILP obj.	Sol. Time (s)	LAG obj.
1. RWA_10-0	31321	10174	7,075,694	1.24	39.77	12	1	16
2. RWA_10-1	33481	10200	7,553,370	1.34	1.51	9	1	12
3. RWA_10-2	51751	20912	11,747,674	2.11	3.75	21	1	21
4. RWA_15-0	233101	89526	53,630,022	1.64	1550	25	1	36
5. RWA_15-1	321301	89960	73,319,650	9.72	7809	26	1	26
6. RWA_15-2	378841	131370	86,900,870	14.39	14086	44	1	44
7. RWA_20-0	1079201	292050	247,779,430				1	27
8. RWA_20-1	1048801	291968	240,958,666				1	39
9. RWA_20-2	1079201	292050	240,958,666				1	28

Table 2. Comparison between ILP and LAG methods

to solve the ILP equations. Table 2 shows the required numbers of variables, constraints, memory and execution time for the ILP methods. From Table 2, we observe that ILP method can only solve the wavelength assignment problem of small networks, i.e., the required memory and execution time of ILP method grows exponentially with the network size. In Table 2, we also show the required execution time and minimum number of wavelengths when LAG heuristic is used for the wavelength assignment. The execution time of LAG heuristic is smaller than one second for all networks, i.e., the execution time of LAG heuristic will not be an important issue even for large networks. The required number of wavelengths solved by LAG heuristic is, in general, greater than that of ILP method because the ILP results are optimal. Owing to the simple iteration clique partitioning method, some LAG results such as network topologies 1, 2 and 4 require 33 to 44 % more wavelengths than that of ILP method. It is expected that we can have much better wavelength assignment result if sophisticated clique partitioning methods is used.

The major advantage of clique partitioning for wavelength assignment is its intuitive relation with the affiliated lightpath group. Besides, LAG ensures that dedicated wavelength is assigned to affiliated customer groups. For example, we can simply apply a graph "cut" as shown in Fig. 1(b) to the basic LAG to have distinct wavelengths assigned to customer A and B. Edges e_{ij} will be removed from the basic LAG (V,E) if lightpaths i and j (v_i and v_j in Fig. 1(b)) belong to different affiliated customer groups. Such arrangement allows flexibility to further tighten the affiliation criteria to suit practical provisioning considerations. Recently, a wavelength assignment method also proposed to apply clique partitioning to solve wavelength assignment in mesh networks [4]. However, the method has not been aware of the relationship between maximum clique and affiliated ligthpath group. If the clique partitioning approach is only used to solve general wavelength assignment problems, we envisage that no special advantage can be obtained as compared to the sophisticated wavelength assignment heuristics [3].

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