



Knapsack based multicast traffic grooming for optical networks



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ABSTRACT

This paper proposes a light-tree based heuristic algorithm, called 0/1 knapsack based multicast traffic grooming, in order to minimize the network cost by reducing the number of higher layer electronic and optical devices, such as transmitters, receivers, and splitters, and used wavelengths in the network. The proposed algorithm constructs light-trees or sub light-trees, which satisfy sub bandwidth demands of all multicast requests. We present a light-tree based integer linear programming (ILP) formulation to minimize the network cost. We solve the ILP problem for sample four-node and six-node networks and compare the ILP results with the proposed heuristic algorithm. We observe that the performance of the proposed algorithm is comparable to the ILP in terms of cost. When the introduced ILP is not tractable for large network, the proposed algorithm still able to find the results. Furthermore, we compare the proposed heuristic algorithm to existing heuristic algorithms for different backbone networks. Numerical results indicate that the proposed heuristic algorithm outperforms the conventional algorithms in terms of cost and resource utilization.

1. Introduction

Wavelength division multiplexing (WDM) is an efficient technology as it supports a huge bandwidth requirement of clients. Based on the observation that the bandwidth requirement of majority of connection requests is much less than the capacity of a wavelength. Therefore, there is a huge gap between the wavelength channel capacity and bandwidth requirement of a connection request. This gap can be managed to incorporate the traffic grooming [1–5] mechanism with an routing and wavelength assignment (RWA) approach [2] where a number of low bandwidth connection requests are multiplexed onto a high capacity wavelength channel to enhance overall channel utilization.

In WDM optical networks, a lightpath [2] is established to carry the information between a source-destination pair. In the absence of wavelength converters, a lightpath must occupy the same wavelength to its end-to-end route; this property is known as the wavelength continuity constraint [6]. In optical network, it is possible that many connection requests share the same source node, but their destination nodes are different. In that case, an individual lightpath needs to be established for each source-destination pairs. This solution is costly, as it requires more number of wavelengths and higher layer devices, such transmitters and receivers. To overcome this issue, the multicast-tree

concept [7,8] is adapted, which supports one to many connections in a single logical hop; it has only a source node and different destination nodes. The multicast-tree reduces average packet hop distance and minimizes the total number of transceivers used in a network. In the logical layer, a light-tree can be represented as a set of directed links from a source node to all required set of destination nodes in the network. Since the transmission from a source node to all the destination sets takes only a single logical hop, this is called logical one hop tree (LOHT) [7]. Low bandwidth connection requests are routed by combining several LOHTs. The combinations of light-trees forms a larger tree than each light-tree. Electronic packet switching with optical-electrical-optical (OEO) conversion is required at the nodes connecting light-trees for forwarding the upstream light-tree to corresponding downstream light-tree(s).

Achieving efficient and effective traffic grooming in WDM optical networks is a challenging research problem. Based on whether connection requests are known to the user a priori, the traffic grooming problem can be classified into two categories, namely static traffic grooming and dynamic traffic grooming. In the static traffic grooming scenario, information about each of traffic request, such as source, destinations and bandwidth requirement, is known to the user in advance. Studies on traffic grooming problem is useful for design and planning purpose. Whereas, in case of the dynamic traffic grooming

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problem, connection requests arrive dynamically based on some distribution process and both routing and wavelength assignment are dynamically decided for new connection requests. In the case of dynamic traffic request, the main objective is to accommodate the traffic requests efficiently and suppress the blocking probability; it is a ratio of the number of blocked requests to the number of offered requests in the network. In our proposed approach, we consider the static traffic scenario under wavelength continuity constraint with all nodes have finite splitting capacity.

In earlier days, traffic grooming in WDM optical networks emphasized to reduce the number of used wavelengths [9,10,5] in order to optimize the network cost. The cost factor not only depends on the number of used wavelengths but also on the number of higher layer electronic and optical devices [7,8,11,12] used in the network. The works in [9,10,5] do not consider the impact of higher layer electronic and optical components on network cost. To overcome this problem, R. Lin, et al. [7] designed a cost effective WDM optical networks with multicast traffic grooming considering higher layer electronic and optical devices along with used wavelengths. They introduced a light-tree based integer linear programming (ILP) formulation in order to minimize the network cost. Since the ILP is intractable for large networks, they introduced a heuristic algorithm, called sub-light-tree saturated grooming (SLTSG), in order to construct sub-light-trees. The overall time complexity of SLTSG is $O(|R|^3 \cdot |V|^4 \log |V|)$, where R and V are sets of multicast requests and nodes in the networks, respectively.

Our objective in this work is to develop a heuristic algorithm for multicast traffic grooming in WDM optical networks considering higher layer electronic and optical devices along with used wavelengths, which requires less computational time compared to SLTSG [7]. To achieve our objective, we propose a heuristic algorithm, called 0/1 knapsack based multicast traffic grooming, which minimizes the network cost. We present a light-tree based ILP formulation to minimize the network cost. By using an optimization solver, we solve the ILP problem for sample four-node and six-node networks and compare the ILP results with the proposed heuristic algorithm. We observe that the performance of the proposed algorithm is comparable to the ILP in terms of cost. When the introduced ILP is not tractable for large network, namely NSFNET [13], the proposed algorithm still able to find the results. Furthermore, we compare the proposed heuristic algorithm to existing heuristic algorithms for different backbone networks. Numerical results indicate that the proposed heuristic algorithm outperforms the conventional algorithms in terms of cost and resource utilization.

The remainder of the paper is structured as follows. Section 2 presents the related works. Section 3 presents the ILP formulation for light-tree based multicast routing, grooming and wavelength assignment. The proposed knapsack based multicast traffic grooming approach for optical networks is presented in Section 4. Section 5 evaluates the performances of the proposed algorithms. Finally, conclusion is drawn in Section 6.

2. Related work

Multicast traffic grooming in WDM mesh networks is well known for its potential to reduce the cost related with the wavelengths requirement for a given network. Taking this direction, the authors in [6] generate multicast tree to establish the connection from the source node to all destination nodes and assign a wavelength in each and every branch of the multicast tree to construct the light-tree. Wavelength continuity constraint is maintained in their work with the objective of minimizing the wavelength usage. Three heuristic algorithms are presented in [14] for wavelength assignment in WDM optical networks with two criterion to cover the maximum number of destinations and to minimize the wavelength cost. The authors in [15] presented two algorithms, which integrate multicast routing and wavelength assignment for optimization of wavelengths used. One

algorithm minimizes the number of wavelengths through reducing the maximal link load in the system while the other does it by trying to free out the least used wavelengths. The different research studies on multicast routing and wavelength assignment can be found in [16,17].

An optimal solution for static traffic grooming can be obtained in [2,3,10] using ILP formulation with the objective of (i) minimizing the network resources used, such as wavelengths, add/drop ports, and transceivers, and (ii) maximizing the network throughput. For static traffic scenario, the grooming is either based on light paths [11,10] or light-trees [18,9,12,19,20]. The authors in [11] introduced a multi-hop static traffic grooming problem based on clique partitioning with the objective of maximizing network throughput for wavelength routed network. A light-tree based ILP formulation has been presented in [7] with the objective of minimizing the cost in terms of higher layer electronic ports and wavelengths and simultaneously introduced a sub-light-tree saturated (SLTSG) grooming algorithm to achieve the scalability. A mixed integer linear programming (MILP) has been reported in [18] in order to solve the optimal routing and wavelength assignment problem of light-trees with end-to-end delay bound, and obtain the optimal placement of power splitters and wavelength converters. The authors in [8] considered multicast traffic grooming problem in tap-and-continue networks where a node can tap a small amount of incoming optical power for the local station while forwarding the remainder to an output, and presented two heuristic algorithms, called multicast trail grooming (MTG) and multiple destination trail based grooming (MTDG), to minimize the network cost, which is associated with transmitters and receivers. The work in [9] constructs the multicast routing trees using first-fit algorithm for traffic grooming; this work also considers wavelength conversion capability of the network nodes. By intelligently grooming of several multicast requests with several sub-wavelengths into a single wavelength channel, their presented approach can significantly reduce the number of used wavelengths. A heuristic algorithm, called saturated-light-tree based multicast traffic grooming (SLTMTG), that solves grooming, routing and wavelength assignment problems with the objective of minimizing the network resources is presented in [12]. A heuristic algorithm, called dividable light-tree grooming (DLTG) [19], is introduced for optimal assignments of hop constrained light-trees for multicast connections in order to maximize the network throughput.

Several studies [21–23,4,24–30] have been performed considering dynamic traffic model in which traffic requests arrive in the network randomly over a period of time and they are served without waiting for future traffic requests. These models are more suitable for the activity mode of WDM optical networks, and hence the network performances in terms of resource utilization and blocking probability are optimized. A generic graph model has been presented in [21] for traffic grooming in heterogeneous WDM mesh networks. In their model, the edges of the auxiliary graph are manipulated to achieve various objectives using different grooming policies, while considering various constraints, such as transceivers, wavelengths, wavelength-conversion capabilities and grooming capabilities. A priority based routing and wavelength assignment scheme with incorporation of a traffic grooming mechanism (PRWATG) [22] is presented to reduce the call blocking. A light-tree based routing scheme for efficient grooming of low bandwidth requirement connection requests on a logical topology of WDM mesh network is introduced in [23]. Two link blocking models, an exact model based on stochastic knapsack problem, and an approximation model based on an approximate continuous time Markov chain (CTMC) [4] have been reported with the objective of improvising the performance of a network by reducing the call blocking probability. Light-tree division adjacent node component based grooming scheme (LTD-ANCG) and light-tree division branch destination node based grooming scheme (LTD-DBNG) are suggested in [24] in order to improve the efficiency of resource utilization and reduction in the optical-electrical-optical (OEO) conversion overhead in WDM mesh networks. A new multicast multi-granular grooming approach is suggested [25] in order to

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