On Multiplexing Optimization in DWDM Networks

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Abstract: We propose a novel graph model for multiplexing optimization in optical networks and evaluate the performance of several multiplexing policies. Simulation shows that our advocated multiplexing policy can provide significant network cost savings.

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1. Introduction

Currently, the operational dense wavelength division multiplexing (DWDM) optical network is able to support up to 100 wavelengths per fiber and 40 Gbps per wavelength, while most connection requests are at much smaller granularities, such as 2.5 Gbps and 10 Gbps. Service providers have to install muxponders at the two ends of the wavelength path to create a multiplexing wavelength connection to provide multiple channels per wavelength. The lower bandwidth connection requests will use these underlying channels. This is called *multiplexing* in DWDM networks. *Multiplexing optimization* is to determine when and where to create high bandwidth multiplexing wavelength connections, which is an important task for cost effective optical network planning. Most of studies in this area focus on either static traffic or dynamic traffic model [1-2]. In this study, we focus on *incremental traffic model,* i.e. low bandwidth connections arrive one by one and are maintained in the network for a relatively long period. This traffic model is more practical for commercial DWDM networks. Also, existing studies in this area seldom consider the optical layer impairments, ASE noise, dispersion, and nonlinear effects. In fact, these effects have significant impacts on the longest distance that an optical signal can travel without regeneration, denoted as *optical reach*, which in turn affects the ultimate network cost [3].

In this paper, we propose a novel multiplexing graph model and multiple multiplexing policies to perform low-bandwidth-connection routing and multiplexing optimization in DWDM mesh networks, combined with the incremental traffic model and physical layer constraints. Based on this graph model, we can automatically determine where to route over the network, where to use existing available multiplexing wavelength connection channels, whether/where to create new multiplexing wavelength connections, where to add regenerators, and what is the overall investment cost: all the information a planner would like to know.

2. Problem Statement and Graph Model

In DWDM networks, wavelength connection cost is usually modeled by two parts: optical transponder (OT) cost and common cost. The OT is an optical-electrical-optical device that is still very expensive. There are two types of OTs, named as term OT and regen OT. When a new wavelength connection is established, a pair of term OTs is required at the two end offices of the wavelength connection. Regen OT, also referred as regenerator, is required when a wavelength connection is longer than the optical reach. Common cost includes optical system device cost, fiber cost, optical amplifier cost, installation cost, etc., and it is averaged as cost per λ_channel-mile. In our multiplexing optimization problem, the objective is to minimize the overall network cost including OT cost and common cost during the lifetime of the DWDM network. For a specific low bandwidth request, there are numerous ways to provision the connection, such as establishing a new long multiplexing wavelength connection directly between source and destination, or reusing some spare channels of existing multiplexing wavelength connections (with/without creating some new short multiplexing wavelength connections). Different decisions may affect future connections. In the incremental traffic model, we know current network status and we need to provision the new connection request without knowing future traffic. Here we propose four multiplexing policies and compare their performances. To accomplish it, we present a novel multiplexing graph model to realize different multiplexing policies by manipulating the cost of graph edges:

Step 1: With the DWDM network physical topology and optical reach, we run the shortest path algorithm to get the distance matrix of all the node pairs in the network. With the distance matrix, we create a new graph ***G(V,E)*** whereas the node set ***V*** is same as that in the physical topology. If the distance of a node pair is not greater than optical reach, we create one direct edge, ***e***, between this node pair. We set its weight ***w(e)*** as one regen OT cost plus its common cost, where the common cost is calculated as its distance mileage multiplied with the per λ_channel-mile cost.

Step 2: If we need to establish new multiplexing wavelength connection between a node-pair where the distance is greater than the optical reach, the most cost-effective way is to route through the shortest path since it requires the least total regen OT cost and common cost. It is easy to verify that the cost to establish a direct multiplexing wavelength connection between a node-pair is the total path weight plus two term OT cost minus one regen OT cost. For all the node pairs with distance longer than optical reach, we find the shortest path over ***G(V,E)***, then create a new edge between them and use the above adjusted path cost as its weight.

With the above the two steps, we build a full mesh graph, named as *multiplexing graph*. The weight of each edge reflects the cost to establish a direct or multiplexing wavelength connection between its end nodes.

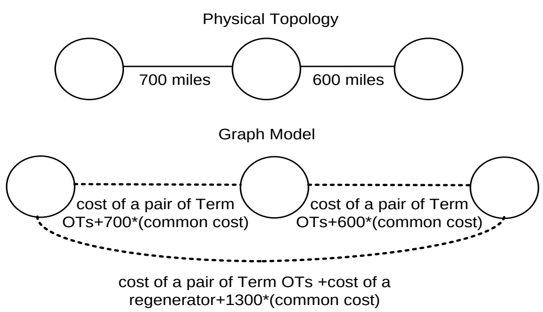

Fig.1. A graph model construction example based on physical topology when optical reach is 1200 miles

Fig.1 shows a sample graph model construction, based on the simple linear physical topology and the 1200-mile optical reach. For simplification, we only consider 10-Gbps connections over 40-Gbps wavelengths while our model can be extended to lower bandwidth connections. Various multiplexing policies can be applied on the same multiplexing graph constructed as above. We treat each potential multiplexing wavelength connection as one link with each link having four channels and build a new graph ***G'(V,E')***, where we create up to 4 links into ***E'*** for each edge ***e*** in ***E*** of ***G(V,E)***. Then we assign different costs to those links according to following four policies and run the least cost routing to select the most cost-efficient route.

Investment cost: the first channel of a multiplexing wavelength connection is responsible for the entire wavelength connection cost and the other channels are free. The reason is that we only need OT capital investment and wavelength resource during multiplexing wavelength connection creation for the first channel request. We assign the total OT cost and common cost to a new multiplexing wavelength connection edge and zero to existing multiplexing wavelength connection edge with available channels. Such a policy tends to attract 10-Gbps connections to use existing multiplexing wavelength connection channels.

Average cost: the four channels share the multiplexing wavelength connection cost evenly. W assign one fourth of the total OT cost and common cost to each channel of the multiplexing wavelength connection including new and existing ones. Such a policy tends to encourage creating new multiplexing wavelength connections everywhere.

Weighted cost: the four channels share the multiplexing wavelength connection cost unevenly, e.g., with the decreasing weights such as 40:30:20:10 for the 1^{st}, 2^{nd}, 3^{rd} and 4^{th} channels. That is, we assign 40% of the total OT cost and common cost to new multiplexing wavelength connection edges, 30% or 20% or 10% of the total cost to existing multiplexing wavelength connection edges with 3 or 2 or 1 free channels, respectively. Such a policy is trying to balance the investment cost and the average cost policies.

Major-Minor cost: The previous three policies do not consider any traffic pattern. In this policy, we first classify network nodes as major or minor nodes. For example, we can classify the top 50% nodes in terms of total historical/forecast traffic as major nodes and others as minor nodes. The major and minor node pairs have different weight-assignment rules. For example, 35:30:20:15 for major to major edges, 60:20:10:10 for minor to minor edges, and 47.5:25:15:12.5 for major to minor edges. The basic idea is to encourage multiplexing wavelength connections between major-major node pair and discourage multiplexing wavelength connections between minor-minor node pair.

With the above multiplexing policies on the same multiplexing graph, first-fit wavelength assignment is used to set up new multiplexing wavelength connections if necessary. After provisioning one new connection we update the graph ***G'(V,E')*** with the possibility to remove some links without available wavelength resources.

3. Evaluation Results

In this section, we present the simulation results of the above four multiplexing policies in CORONET [4] topology and the corresponding traffic pattern. Note that, the traffic here refers to the wavelength service traffic only supported by a set of nodes within the topology. In the CORONET topology, there are 100 nodes globally, and 40 of them support wavelength services. For our simulation, we consider only those nodes and links within US, including 74 nodes, 96 links and 30 nodes with wavelength services, and 16 nodes are classified as major nodes. Also, we assume each link represents one pair of fiber between the two end nodes, and each fiber can accommodate 100 wavelengths. To evaluate the overall cost, we normalize the term OT cost, regen OT

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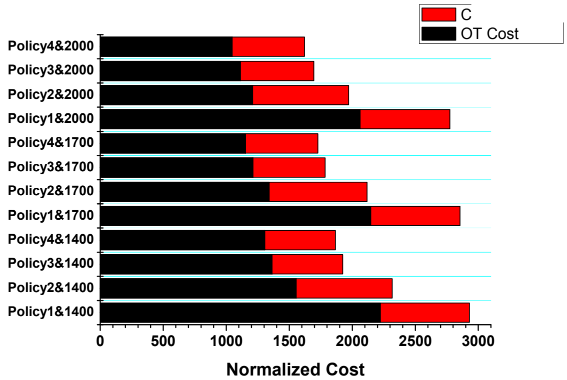

Fig. 2. Nomalized network cost of four policies with different optical reaches

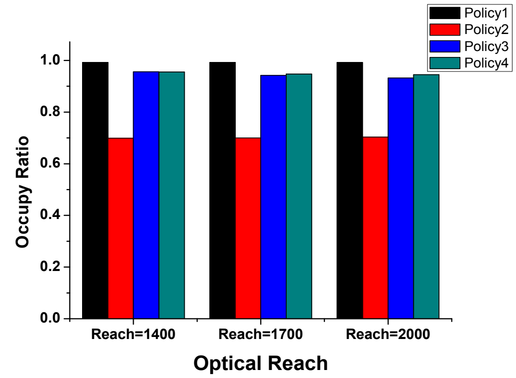

Fig. 3. Channel Occupy Ratio of four policies with different optical reaches

cost and common cost to be 0.75,1 and 0.0006/λ_channel-mile based on our study on commercial networks. As for the input traffic from CORONET project, we randomly generate 10-Gbps connections using CORONET traffic matrix and route them one by one under different multiplexing policies. We collect both OT cost and common cost of the four policies in three different cases, where the optical reach is set to be 1400 km, 1700 km and 2000 km, as shown in Fig. 2. Also, we calculate the occupancy ratio of the four policies with different optical reaches, defined as the number of channels actually used over the total channels provisioned via multiplexing wavelength connections, as shown in Fig. 3. Each case, we simulated 100 times and average results which is in 95% confidence interval.

4. Discussion

From our performance evaluation results, we noticed that both investment cost policy and average cost policy do not perform well compared with weighted cost and major-minor cost policies, since investment cost policy will route long path to use existing multiplexing wavelength connections without considering future connection requests, confirmed by the highest occupancy ratio of channels shown in Fig. 3. Average cost policy will try to create multiplexing wavelength connections between any two network nodes to route over shortest path. This method inevitably causes lower channel occupancy ratio, illustrated in Fig. 3. This policy may have smallest cost for connection request on average, but due to low occupancy ratio, the total cost is still high. Weighted cost policy is trying to make a balance between investment cost policy and average cost policy while major-minor cost policy encourages more multiplexing wavelength connections between major-major network nodes and few multiplexing wavelength connections between minor-minor network nodes. This policy matches planners' intuition well. With the well-tuned weights for major and minor offices, it should and does outperform other policies.

We applied the same set of multiplexing policies on to a commercial service provider's DWDM network with real traffic numbers and results in the same observation on both total cost and occupancy ratios. In fact, the major-minor cost policy has been implemented in AT&T internal optical network planning tool, named as *BIRDSEYE*.

5. Summary

This paper deals with a complex problem that carriers are facing, routing lower speed connections over high speed DWDM networks. We propose a new multiplexing graph model incorporating the physical layer constraints. By manipulating graph edge cost, we can easily achieve different objectives using different multiplexing heuristics. Based on this model, we propose several multiplexing policies and evaluate their performances using CORONET network topology and traffic as well as a commercial network topology and traffic. The results show that our proposed major-minor cost policy can provide significant network cost savings compared to other policies.

6. References

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