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Multi-Layer Capacity Planning, Cost Modeling and Optimization

A Technical Paper prepared for the Society of Cable Telecommunications Engineers
By

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Overview

The capacity planning and optimization task is often segmented on the basis of network architecture and technology, e.g., backbone vs. access, and IP vs. optical. Multiple data sources, e.g., SNMP, NetFlow, DPI, IPDR, and service offerings, e.g., HSD, fiber, residential, commercial, Wi-Fi, video, further section the methodology and process.

It is desirable to take a holistic approach so that network capacity can be planned and optimized across the multiple boundaries in architecture, technology, data sources and service offerings. This paper introduces the current state of the art in the unification of network modeling, capacity planning, cost modeling and optimization across one of the big divides in network architecture, IP layer vs. optical layer.

In a typical service provider environment, there is often a clear demarcation between IP layer, i.e., layer 3, and optical layer, i.e., layer 1, in terms of organizations and functions for network engineering and capacity planning. Different groups with various methodologies and tools plan and optimize each layer individually. There is opportunity in collaboration between the two efforts, but it is often limited. In the end, while each layer can indeed and often be optimized (subject to skill and tool limitations), the combination of two layers as a whole is far from optimal.

This paper illustrates an approach to expand auto discovery and modeling of a network modeling tool from IP layer to the optical layer. The result is a multi-layer network model. Given a set of traffic demands, an optical topology, and a cost function, the modeling tool generates hundreds of thousands candidate IP topologies, performs exhaustive failure simulation, and score each candidate with the cost function. The end result is a least cost, among the numerous candidates, multi-layer design supporting the traffic demand and failure criteria.

The methodology, tools and process to successfully perform multi-layer network modeling, planning, and optimization are presented. Analytics results from a real backbone network are provided to illustrate the benefit of this holistic approach. Common challenges are discussed, and mitigation strategies are discussed.

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Multi-Layer Capacity Planning

Nowadays, the High Speed Internet service becomes an increasingly important revenue source for most MSOs. Some large MSOs built their own backbone to transport Internet data among their market footprints. Because of the increased use of the Internet by subscribers, the Internet traffic grows year over year. Cisco predicted 23% annual growth from 2012 to 2017 [1]. To handle the increased traffic, MSOs' backbone needs to grow their capacity as well. Careful capacity planning is required to add enough capacity at right place and right pace.

Behind the scene of an MSO's IP backbone, there are routers, optical equipment, optical fibers and other ancillary equipment. The main job for a capacity planning team is to understand the capacity constraints of the physical equipment and to measure their current utilization [2]. However, it remains challenging to plan capacity cross different technology and organizational boundaries. It is because an IP backbone is designed with a layered architecture [3, 4]. The technology, knowledge and expertise required to manage routers are completely different from managing optical equipment. Thus for most Internet service providers, especially large ones, they often have different team and different tools to manage routers and optical equipment separately. In such environment, it usually requires significant efforts to coordinate different groups for capacity planning.

Typically, the process starts with the capacity requirements analysis between router pairs, or at router layer (or layer 3, or IP layer). Such requirement in turn will become the input to the capacity planning between optical equipment pairs, or at optical layer (or layer 1). One of the big challenges is to map a router end point to an optical end point. Such mapping will "glue" router layer and optical layer together to form a holistic view, illustrated in Figure 1.

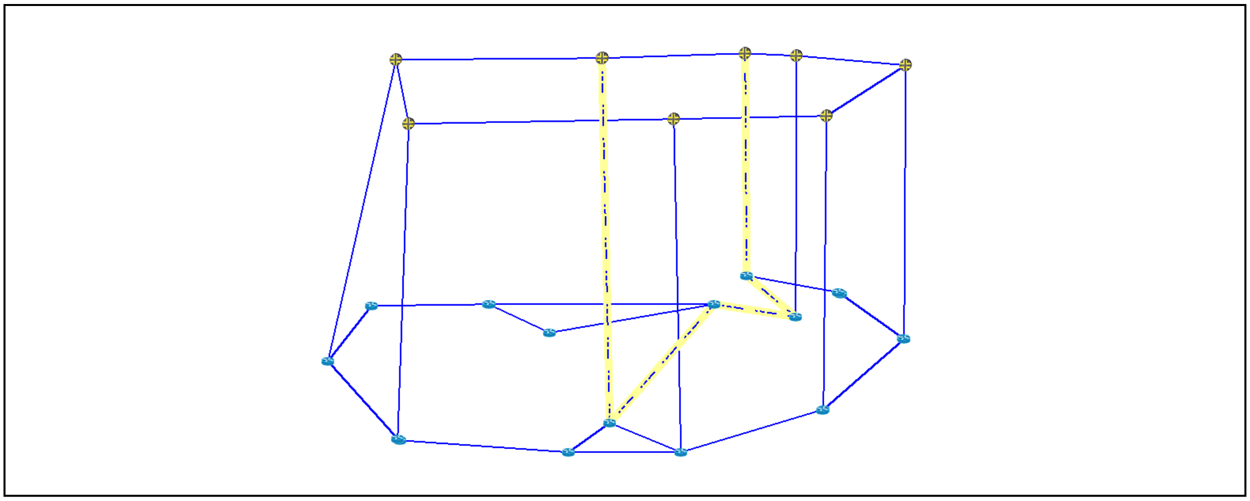

Figure 1. Illustration of Multi-Layer View of an IP Backbone. The yellow icon represents a router, while the blue icon represents an optical equipment. The yellow dotted lines illustrate mapping between two layers.

There are two ways to map a router end point to an optical end point. One way is to create and to maintain a mapping table manually. Depending on the size of the backbone and organizational structure, as stated earlier, it usually requires significant coordination efforts to create such a mapping table and to keep it up to date and error free.

The other way is to exploit network modeling tools to automate the work. The first step is to model a backbone at both layers. It is relatively easy to model a layer 3 network with existing commercial tools. However, there are very few third-party vendor-neutral tools available in the market to model an optical network. Rather most network operators rely on the optical equipment vendors' Element Management System (EMS) to operate their optical network. Optical EMSs are often closed systems with limited or no API for external use. In a multi-vendor environment, it is even more challenging to orchestrate multiple optical EMSs. Our experiment with a single vendor showed that the optical EMS can export sufficient information for automated layer 1 discovery and modeling. With some efforts, such export information can be extracted to create a layer 1 model.

The next step is to stitch the two models together. However, there is no standard way of doing it. Instead, it is largely depending on how a network is managed. In our case, our optical engineers always add a piece of layer 3 information into EMS database whenever a new optical wavelength is put in use. That information becomes crucial to connect everything together. Figure 1 shows a multi-layer view of an example network as an outcome from this effort.

With a multi-layer model, it is possible to directly translate layer 3 capacity requirements to layer 1, without too much coordination efforts. Moreover, it is also possible to automatically generate Shared Risk Link Group (SRLG) by examining each optical segment and all layer 3 circuits traversing that segment. SRLG is known for playing an important role for failure simulation and capacity analysis. Last but not the least, a multi-layer model introduces new opportunity for network optimization, as we will discuss later.

Cost Modeling

One step beyond the capacity planning is the budget planning, which takes capacity requirements as an input and translates it into equipment and service cost. If the two planning processes were combined, it may provide an extra viewpoint to examine the network growth from CAPEX-efficiency perspective. To meet the same traffic demand, there are multiple capacity augmentation options. By evaluating the cost and constraints of each option, one can pick the option with minimal the cost while satisfying the performance constraints.

However, it is very challenge, if not impossible, to build a cost model to include every detail and to reflect every aspect of a network. We found it only can be approximated by using abstraction methodology. For example, the blended costs are used to formulate the costs of multiple items into few representative ones. Moreover, a network is abstracted as a system consisting of few most relevant elements such as router, OADM, and wavelength. A router is further abstracted as a set of IP ports. In reality, a router also includes many other parts like chassis, line card, routing engine, power supply and so on, but the cost to those components are blended into the cost of IP ports. In this paper, each IP port cost X amount of money. Similarly, an OADM is abstracted into a set of wavelength, each not only has a fixed cost of Y, but also another cost factor Z which is proportional to the distance a wavelength travels. Figure 2 depicts such an abstracted network model and its associated cost model.

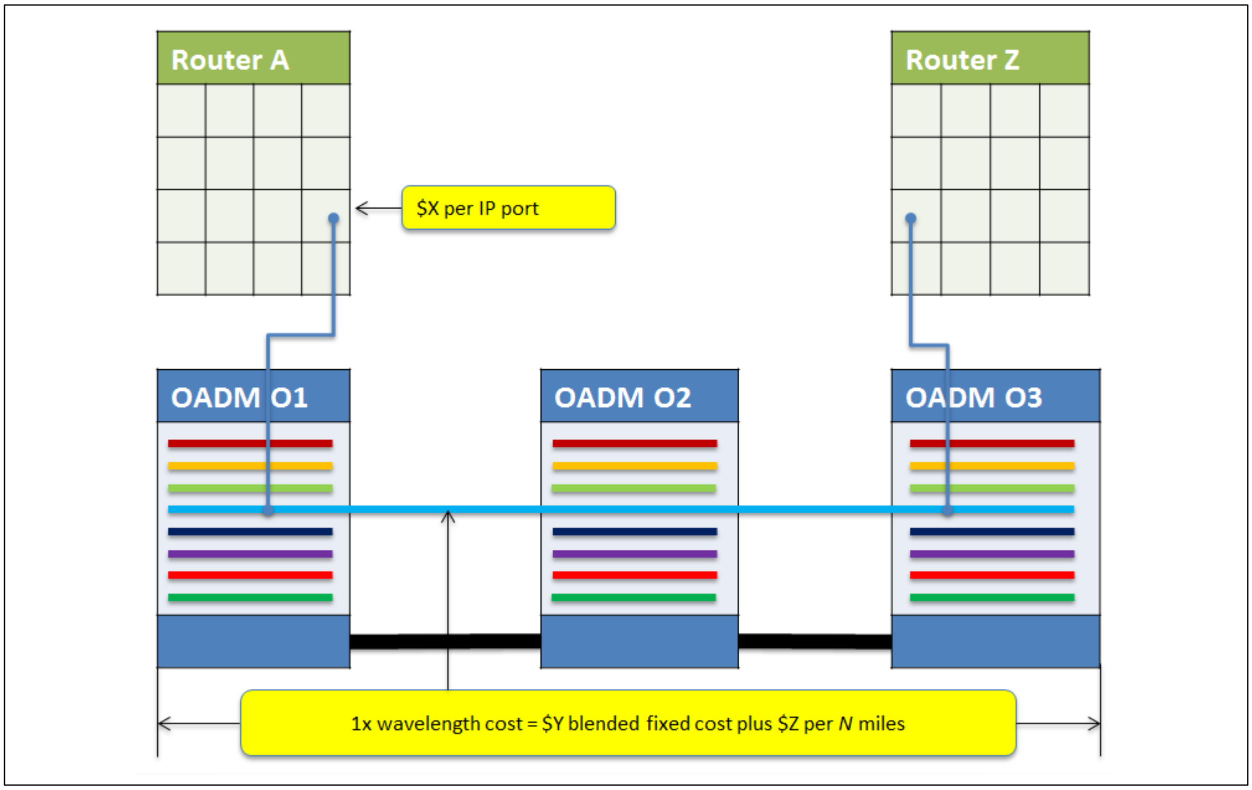

Figure 2. Network Abstraction and Cost Modeling. Each router is abstracted as a set of IP port, each costs $X. Each OADM is abstracted as a set of wavelength, each costs $Y plus a variable cost $Z proportional to the distance.

With such abstraction, the cost to an IP link between a router pair can be derived as the following:

$$Cost(IP\ link) = 2X + Y + Z*distance$$

A network now can be viewed as a number of IP connections. By summing up all the costs of IP connections, it will be the total network cost.

$$Cost(network) = \sum Cost(IP\ link\ L_i)$$

To validate the cost model built from above abstraction approach, the external data source is sought to make a comparison. The financial data is an excellent choice because it reflects the actual spending to build and to augment a network. A particular metric used by our finance group is the network cost to transport per Gbps of traffic, denoted by *C/b*[1] in this paper. *C/b* is calculated from dividing the total network cost by the total customer traffic traversing the network. We compared *C/b* provided by the finance department and *C/b* calculated from the capacity plan based on the cost model,

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[1] Please note that *C/b* usually not only reflects the cost to transport customer traffic from one place to another, but also the cost to provide the redundancy to handle failure events, because very few networks are built without considering potential failures.

and two numbers are very close. It shows a lot of promise to create a valid cost model by applying abstraction approach.

Network Optimization

With multi-layer modeling and cost modeling, it is now possible to rethink the network optimization from CAPEX-efficiency perspective. Today, a network is often designed and implemented by different groups. For example, IP engineers design layer 3 while optical engineers focus on layer 1. However, such parallel efforts may not produce the optimal results. It makes more sense to view both layers as a whole because they are correlated through traffic. The traffic typically traverses from a router to an optical gear, then be transmitted over an optical fiber to a remote optical gear, then goes up to another router. Such traffic pattern defines an internal relationship between two layers which will be left out when a network were designed separately at different layers.

Such practice often results in sub-optimal network architecture and capacity plan. The commonly used optical bypass technology [5], which provides a direct optical path between two distant routers without touching layer 3 routing domain, is a good example. Optical bypass is often considered as a cost-saving choice because it cuts the costs of transponders and IP ports. However, in some failure cases, using optical bypassed IP link as a backup path may not be efficient. Figure 3 illustrates such a case where the IP link between A and B fails because of a bad IP port. In this case, the optical layer stays intact so A is still able to reach C. Based on the routing, A will reroute to C to reach B, so the traffic will be delivered from A to C then from C to B. However, because A-C link is optical bypassed, traffic will actually go through same fiber between B and C twice. The fiber capacity between B and C has to be doubled to handle such failure case.

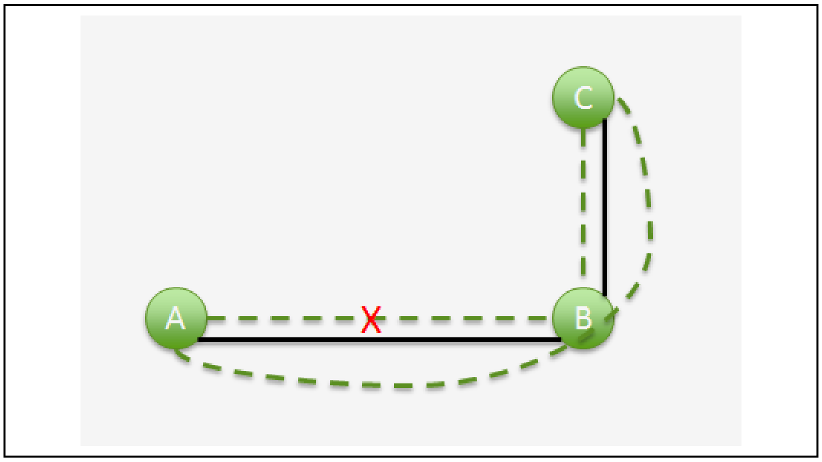
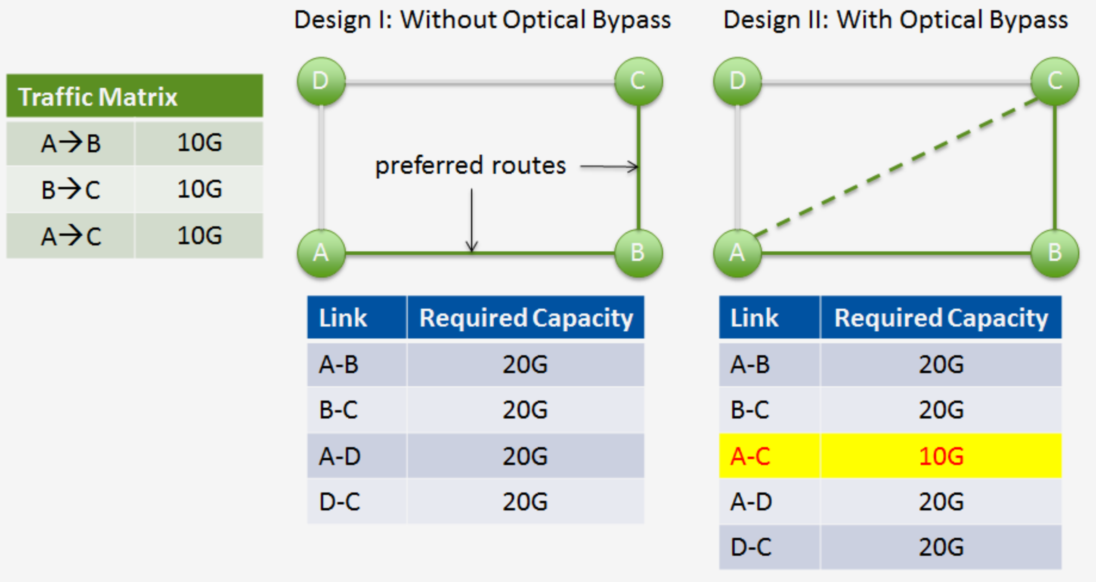


Figure 3. An example case illustrating using optical bypassed route as backup path may double the capacity requirement. A circle represents a router and a black solid line represents optical fiber. A green dotted line is an IP link.

Figure 4 illustrates yet another example. In this example, we will design a 4-node network to satisfy a given traffic matrix. Also it is assumed that the design goal is to handle any IP link failure and any fiber cut. There are two design options. Design option I does not include any optical bypassed IP link. Design II includes one optical bypassed IP link between A and C. The required bandwidth capacity per IP link is obtained by examining all possible failures. Comparing two designs, design II with optical bypass actually requires more capacity.



Traffic Matrix	
A→B	10G
B→C	10G
A→C	10G

Design I: Without Optical Bypass

Link	Required Capacity
A-B	20G
B-C	20G
A-D	20G
D-C	20G

Design II: With Optical Bypass

Link	Required Capacity
A-B	20G
B-C	20G
A-C	10G
A-D	20G
D-C	20G

Figure 4. An example case illustrating optical bypass sometimes may introduce extra costs. Each circle represents a router and each solid line represents both an IP link and the underlying optical fiber. The dotted line represents an optical bypassed IP link. The green lines are the preferred route carrying traffic in normal states. The gray lines are the backup paths.

As a summary, the impact to the total network cost by optical bypass is twofold. In some cases, optical bypass cuts the cost by reducing use of transponders and IP ports. However, in some other cases, it may introduce extra costs. It will require considerable amount of failure simulation to understand the actual cost impact by optical bypass technology.

Therefore, when designing a network, a combined multi-layer view becomes even more important. One cannot freely design a layer 3 network without considering constraints posed by layer 1, such as twofold aspect of optical bypass. Fortunately, there are tools available now to perform multi-layer design and optimization. By using such tools to examine TWC IP backbone, we are able to find 10%+ CAPEX savings.

Conclusion

The modeling and optimization of a typical service provider's backbone network today far exceeds what can be achieved through manual or spreadsheet exercises. While layer 3 modeling with network modeling tools is commonplace for service providers large and small, multi-layer modeling and planning (especially with auto-discovery) is significantly more challenging and much less successfully executed. In this paper, we share the experience of our multi-layer modeling initiative.

With the development of automated parsing of database export from optical EMS, the optical topology is auto discovered and layer 1 model is built accordingly. Layer 1 model is then auto stitched to the layer 3 model through IP layer tags encoded in the optical EMS. The completed multi-layer model provides a platform for unified network optimization based on cost and other design criteria such as latency bounds.

A blended and simplified cost function based on the constructs of layer 3 link and layer 1 wavelength is developed. Evaluating capacity plans based on the cost function with actual finance data from prior years further validates the fidelity of the cost function.

With the multi-layer model and cost function, the network modeling tool performs exhaustive failure simulations on hundreds of thousands auto generated candidate layer 3 topologies, and score each candidate with the cost function. The end result is a least cost, among all candidates, multi-layer design supporting the traffic demand, the failure criteria, and the design goal.

With this approach, we were able to come up with an optimized layer 3 design resulting in 10%+ CAPEX saving. There is also significant insight gained on optical bypass and its capacity impact. We plan to expand this initiative to cover optical gears from multiple vendors. This will allow us to expand the exercise to other network segments beyond backbone. We also plan to augment the multi-layer model with a cost function of end-to-end demand. This will allow us to model and price the cost of peering arrangements and service offerings.

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Abbreviations and Acronyms

API	Application Programming Interface
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
DPI	Deep Packet Inspection
EMS	Element Management System
HSD	High Speed Data
IP	Internet Protocol
IPDR	Internet Protocol Detail Record
OADM	Optical Add/Drop Multiplexer
OPEX	Operational Expenditure
SNMP	Simple Network Management Protocol
SRLG	Shared Risk Link Group