A Customizable Two-Step Framework for General Equipment Provisioning in Optical Transport Networks

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***Abstract*—Optical Transport Network (OTN) is a standard approach to offering transport support to a variety of existing service technologies, e.g., ESCON, HDTV, GE, etc. Multiple service technologies can be concurrently multiplexed onto one common transport network, which offers hierarchical transmission rate wrappers physically supported by Wavelength Division Multiplexing (WDM) lambda channels. Algorithms to perform grooming and routing in OTN are expected to be complicated due to the large number of grooming options that are available in the standard. In addition, these algorithms are likely to be designed by the vendor engineers, who have full knowledge of the grooming, switching, and routing capabilities of their own equipment.**

Yet the authors of this paper propose a relatively simple algorithm framework for equipment provisioning in OTN that can be customized by the network designer. Taking advantage of the multi-rate nature of supported services in OTN, traffic demands can be divided into two groups based on their bandwidth requirement. Demands with bandwidth request below a bandwidth threshold are placed on newly provisioned resources and demands with bandwidth request above the threshold are preferably routed over already provisioned resources. The latter procedure is more time consuming but yields more efficient traffic grooming when compared to the former procedure. The bandwidth threshold can be set by the network designer either to decrease running time of the algorithm, or conversely, to increase optimality of the solution found.

I. Introduction

Optical Transport Network (OTN) — defined by ITU-T G.709 standard [1] — is a next-generation optical network architecture designed to concurrently carry a variety of multi-rate services on a common substrate, such as SONET/SDH, ATM, IP/Ethernet, etc. A group of these services may be multiplexed (groomed) together to be jointly carried by one OTN carrier, which in turn may be supported by a wavelength channel. As a result, together with Wavelength Division Multiplexing (WDM) technology, OTN offers to many services a common transparent optical transport technology, that is scalable and relatively simple due to its hierarchical structure. The availability of a common and single transport technology — along with transparent support for legacy technologies — may greatly reduce equipment cost and management complexity of the overall network system.

ITU-T G.709 defines the Optical Transport Unit (OTU) frame as the basic transmission unit and offers three line rate options: 2,666,057 kbit/s (OTU1), 10,709,225 kbit/s (OTU2) and 43,018,413 kbit/s (OTU3). The OTU frames offer multiple hierarchical "wrappers" to contain various types of service, such as Enterprise Systems Connection (ESCON), High-Definition Television (HDTV), Gigabit Ethernet (GE), Fiber Channel (FC), etc. The variety of services that can be groomed and routed over OTN represents a challenging problem to the network designer who must choose how to provision equipment in the OTN layer in a cost effective way. First, services that need to be groomed are diversified, making the selection of the appropriate equipment difficult. Second, multiplexing of services with different bandwidth at intermediate network nodes might be needed to reach appropriate transmission rates in specific network segments, e.g., multiplexing of four OTU1 frames into OTU2, where the former is used in peripheral networks and the latter is used in the core. Finally, there is a variety of OTN equipment, such as OTU line cards and Wavelength Cross-connects (WXCs), whose characteristics and functionalities highly vary from vendor to vendor. Based on these observations, algorithms to perform grooming and routing in OTN are anticipated to be complicated.

Commercially available network planning tools [2] compute capacity requirements, but tend not to account for specific equipment constraints. For example, they do not map specific service traffic onto line cards, ports, etc., as this mapping is typically done by a follow-up step, typically vendor specific. Algorithms for grooming and routing in OTN are thus likely to be designed by vendor engineers, who have full knowledge of the grooming, switching and routing capabilities of their own equipment. Although traffic grooming in WDM networks has been studied extensively in the recent years [3], [4], [5], [6], OTN specific results are quite limited.

In this paper, the authors propose a programmable *2-step algorithm framework* that can assist the network designer in performing equipment provisioning in OTN. The main objective of the framework is to determine OTN equipment that must be provisioned to carry a given set of services and mapping of the services onto appropriate OTN equipment is provided as part of the framework output. The framework is designed to work with a general set of OTN equipment, and can be customized by the network designer to account for vendor specific equipment functionalities and constraints. Thanks to its 2-step structure, the framework is fine tunable, in that the first step is optional, which can be applied to increase optimality of the solution found, or conversely, skipped to decrease running time of the algorithm. If this step is applied, services are first carefully routed over already provisioned equipment — a time consuming procedure, which yields improved grooming efficiency. Otherwise, services are routed using lightpaths [7] at the WDM layer — a time efficient calculation, which does not take full advantage of available resources already provisioned in OTN. It is up to the network designer to decide which type(s) of services is (are) subject to the former step, and which one(s) is (are) not.

II. The OTN Standard and the Provisioning Algorithm Framework

This section first provides a brief description of the services and the OTU wrappers defined in OTN. Then the algorithm framework for OTN equipment provisioning is presented.

A. Services and OTU Wrappers

Available line rates (OTU1, OTU2 and OTU3) in OTN, along with their respective wrappers and service types are shown in Fig. 1. Some services (ESCON, FDDI, GE) can be carried by ANY wrappers, which require sub-OTU1 capacity. In turn, a group of ANY services can be groomed together to be carried by a single OTU1 frame. Services (10GE, STM-64) requiring higher bandwidth can be carried by higher line rates, e.g., OTU2.

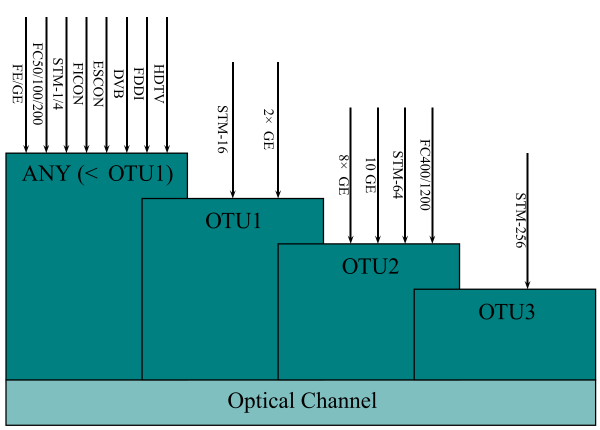
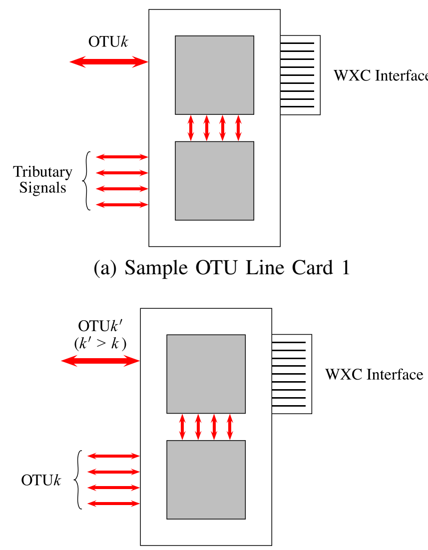


Fig. 1: Services and OTU Wrappers in OTN.

B. 2-Step Provisioning Algorithm Framework

The proposed algorithm framework is based on the assumption that the WDM layer design (i.e., transmission line, routing and wavelength assignment for lightpaths, and optical cross-connect configuration) is performed by a separate module, which computes the cost of establishing a lightpath between any pair of OTN nodes. Objective of the algorithm framework is then to provision OTN equipment needed in the network to carry a set of given heterogenous services.



(a) Sample OTU Line Card 1

(b) Sample OTU Line Card 2

Fig. 2: Sample OTU Line Cards.

In order to make the algorithm generic (hence compatible with most existing OTN equipment products), only a few assumptions are made:

- OTU line cards which have the capability to aggregate and disaggregate various tributary signals, e.g., HDTV, GE, FC and STM-i into appropriate OTUk signals, are available (Fig. 2a);
- OTU line cards, which have the capability to aggregate and disaggregate OTUk signals into appropriate OTUk' signals, are available (Fig. 2b);
- WXCs which are compatible with the OTU line cards defined above, are available.

The algorithm framework consists of two steps (Step 1 and Step 2) and works as follows. All services are first sorted according to their bandwidth requirement in decreasing order and then assigned OTN resources one by one. Services are assigned OTN resources using Step 1 first; if Step 1 fails to do so, then Step 2 is applied. Step 1 is an optional step and is significantly more intensive in computation than Step 2, so it is up to the network designer to decide which service should go through this step. One way to choose what kind of services should take this step and effect of the choice on the algorithm performance is discussed in Section III-B.

Step 1: In this step, only already provisioned OTN equipment are considered to carry the service. The service route is computed to minimize cost of OTN resources that must be assigned to the service. Step 1 consists of:

1) An auxiliary graph is created by adding one vertex for each already provisioned OTU line card in the network that has enough unassigned capacity to carry the service.
2) A bidirectional edge with weight 1 is added between two vertices if the OTU line cards represented by the vertices are either directly connected by a lightpath at the WDM layer or connected through a common WXC.
3) Shortest paths are computed between all the vertices representing the OTU line cards already provisioned at the service source to all the vertices representing the OTU line cards already provisioned at the service destination.
4) The path with the minimum weight among all the shortest paths computed is chosen, and bandwidth required by the service is assigned to the service in all OTU line cards represented by the vertices in the path.

Step 2: If Step 1 fails or is skipped, this step provisions OTN equipment needed to accommodate the service. OTN equipment is provisioned while accounting for the minimum cost of establishing additional lightpath(s) required to connect the OTN equipment across the network. Step 2 comprises two subroutines: the first subroutine creates an auxiliary graph that keeps track of a subset of available and potentially good options for adding OTN equipment to the network; and the second subroutine chooses the option in the subset that has the minimum cost. A description of the two subroutines is provided next.

Substep 2.1: Creating the auxiliary graph

1) An auxiliary graph is created by defining one distinct vertex to represent each WDM network node, and connecting pairs of such vertices with bidirectional edges if the two corresponding WDM nodes can be directly connected by at least one newly created lightpath. The weight of the edge is chosen to represent the cost of establishing the lightpath. Define as source the vertex that represents the WDM node where the service originates. Define as destination the vertex that represents the WDM node where the service terminates. The shortest path is computed from source to destination.
2) Considering only the WDM nodes along the computed shortest path, a second auxiliary graph is created as follows. A vertex is created for every OTU line card that is already provisioned at each WDM node and that has sufficient unassigned capacity to carry the service.
3) The second auxiliary graph is enriched with additional vertices that represent *virtual OTU line cards*. A virtual OTU line card is defined as a OTU card that is not yet provisioned in the network, and could be added to support the service under consideration.
4) The second auxiliary graph is enriched with a bidirectional edge between any pair of vertices representing OTU line cards that are directly connected via either a lightpath or a WXC. The edge weight is computed as follows: 0 if both vertices represent already provisioned OTU line cards; 2 if both vertices represent virtual OTU line cards; and 1 otherwise (i.e., one vertex represents an existing OTU line card and the other vertex represents a virtual card).

Substep 2.2: Computing the minimum cost option

1) Shortest paths are computed from all the vertices representing OTU line cards that are at the service source to all the vertices representing OTU line cards that are at the service destination.
2) The path with the minimum weight among all the shortest paths computed is chosen. Any virtual OTU line card (vertex) in the chosen path is provisioned and a bandwidth amount equal to the service bandwidth is reserved in all of the OTU line cards represented by the vertices in the path.

To better illustrate two steps of the algorithm, two examples are shown in Fig. 3. In the first example (Fig. 3a), the cost of creating a lightpath between any node pair is 2. A lightpath between node A and node B and a lightpath between node B and node C are already created and OTU line cards 1, 2, 3, and 4 are already provisioned and each of these line cards has 2 Gbit/s of unassigned capacity. A GE tributary service (1 Gbit/s bandwidth) must be carried from node A to node C. If Step 1 is applied, then the path from card 1 to card 4 is found via node B. If Step 1 is skipped and Step 2 is applied, a newly created lightpath is established directly between node A and node C, along with the provisioning of additional OTN equipment (cards 5 and 6).

In the second example (Fig. 3b), A lightpath between node A and node B and a lightpath between node B and node C are already created and OTU line cards 1 and 2 are already provisioned and each of these line cards has 2 Gbit/s of unassigned capacity. A GE tributary service must be carried from node A to node C. Step 1 fails to find a solution using already provisioned equipment only. Step 2 creates a new lightpath between node B and node C and finds one path from node A to node C: $1 \to 2 \to 3 \to 4$, for which two new cards (3 and 4) are needed; thus the path is chosen and 2 new cards are allocated along this path.

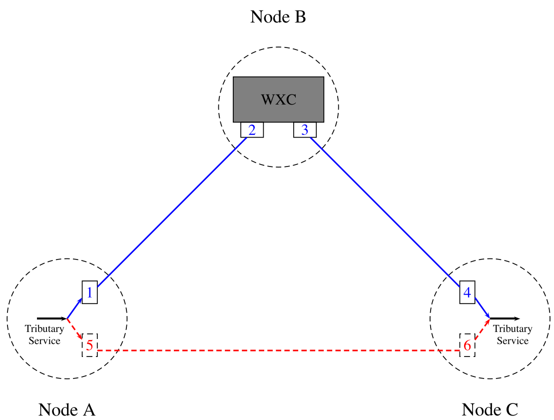
The pseudo code of Step 1 and Step 2 is given below using the following notation:

- s: source of service;
- d: destination of service;
- b: service bandwidth;
- C: set of all OTU line cards already provisioned in the network;
- $c_i \in C$: the i^{th} OTU line card in set C;
- $A(c_i)$: unassigned capacity of card c_i.

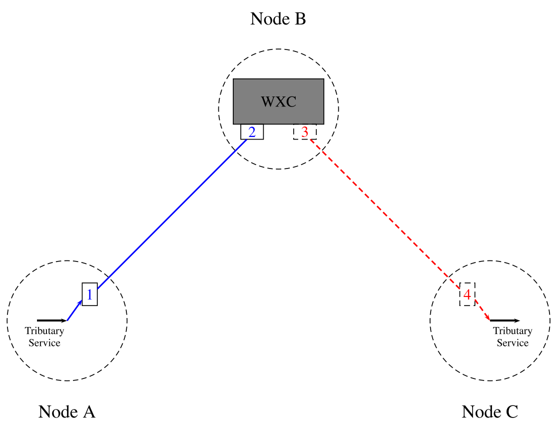
An indicator function is defined as follows:

$$I(c_i, c_j) = \begin{cases} 1 & \text{if } c_i \text{ and } c_j \text{ are connected by a lightpath} \\ & \text{in WDM layer or } c_i \text{ and } c_j \text{ are connected} \\ & \text{to the same WXC,} \\ 0 & \text{otherwise.} \end{cases}$$

Step 1:



(a) Example 1



(b) Example 2

Fig. 3: Illustrations of the Algorithm.

create a graph $G(V, E)$, $V \leftarrow \emptyset$, $E \leftarrow \emptyset$
create two vertex sets S and D, $S \leftarrow \emptyset$, $D \leftarrow \emptyset$
For $c_i \in C$
    If $A(c_i) \geq b$
        create a new vertex v_i, $V = V \cup v_i$
        If c_i is located at s
            $S = S \cup v_i$
        ElseIf c_i is located at d
            $D = D \cup v_i$
        EndIf
    EndIf
EndFor
For all (v_i, v_j) pairs $(v_i, v_j \in V, i \neq j)$
    If $I(c_i, c_j) = 1$
        create a new edge e_{ij} between v_i and v_j with weight 1
        $E = E \cup e_{ij}$
    EndIf
EndFor
create a path set P, $P \leftarrow \emptyset$
For all (s_i, d_j) pair $(s_i \in S,\ d_j \in D)$
    compute shortest path from s_i to d_j on G, denoted as p_{ij}
    $P = P \cup p_{ij}$
EndFor
If $P \neq \emptyset$
    $p_{\min}$ = the path with minimum weight $\in P$
    For vertex $v_i \in p_{\min}$
        put the service into c_i
    EndFor
Else
    go to **Substep 2.1**
EndIf

Substep 2.1:

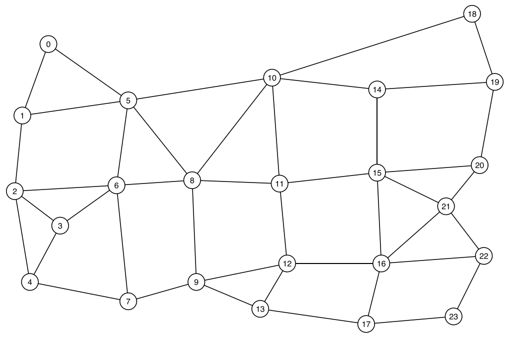
compute the shortest path from s to d in WDM layer, denoted as p
create a graph $G(V, E)$, $V \leftarrow \emptyset$, $E \leftarrow \emptyset$
create three vertex sets S, D and V_n, $S \leftarrow \emptyset$, $D \leftarrow \emptyset$, $V_n \leftarrow \emptyset$
For each node $n \in p$
    For c_i located at n
        If $A(c_i) \geq b$
            create a new vertex v_i, $V = V \cup v_i$
            If $n = s$
                $S = S \cup v_i$
            EndIf
            If $n = d$
                $D = D \cup v_i$
            EndIf
        EndIf
    EndFor
    If $n = s$
        create a new vertex v_n, $S = S \cup v_n$, $V_n = V_n \cup v_n$
    ElseIf $n = d$
        create a new vertex v_n, $D = D \cup v_n$, $V_n = V_n \cup v_n$
    Else
        create two new vertices v_n and $v_{n'}$, $V_n = V_n \cup v_n \cup v_{n'}$
    EndIf
EndFor
For all (v_i, v_j) pairs $(v_i, v_j \in V, i \neq j)$
    If $v_i \notin V_n$ and $v_j \notin V_n$
        If $I(c_i, c_j) = 1$
            create a new edge e_{ij} between v_i and v_j with weight 0
        EndIf
    ElseIf $(v_i \in V_n$ and $v_j \notin V_n)$ or $(v_i \notin V_n$ and $v_j \in V_n)$
        If v_i and v_j are located on the same node in the network
            create a new edge e_{ij} between v_i and v_j with weight 1
            $E = E \cup e_{ij}$
        EndIf
    Else
        If v_i and v_j are located on the same node or nodes at which v_i and v_j are located are connected by a lightpath in WDM layer
            create a new edge e_{ij} between v_i and v_j with weight 2
            $E = E \cup e_{ij}$
        EndIf
    EndIf
EndFor

Substep 2.2:

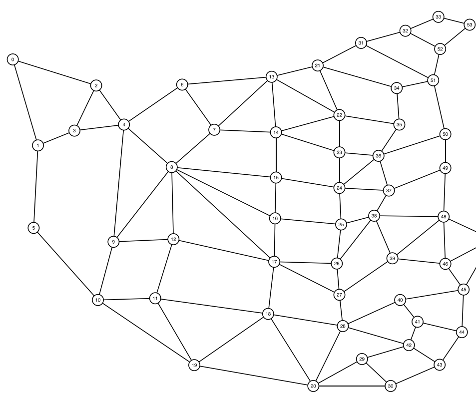
create a path set P, $P \leftarrow \emptyset$
For all (s_i, d_j) pair $(s_i \in S,\ d_j \in D)$ in G created in **Substep 2.1**
    compute shortest path from s_i to d_j on G, denoted as p_{ij}
    $P = P \cup p_{ij}$
EndFor
If $P \neq \emptyset$
    $p_{\min}$ = the path with minimum weight $\in P$
    For vertex $v_i \in p_{\min}$
        If $v_i \in V_n$
            add a new OTU line card c_i
        EndIf
        put the service into c_i
    EndFor
Else
    return "service cannot be allocated"
EndIf

III. Simulation Results

The equipment provisioning algorithm framework described in Section II-B is tested using a WDM/OTN planning tool [8]. Two network topologies are used in the experiments: network 1 is the American network backbone with 24 nodes and 43 links (Fig. 4a); network 2 is the Chinese network backbone with 54 nodes and 103 links (Fig. 4b). The service traffic used in the two experiments consists of point-to-point bidirectional services that are uniformly distributed among the network nodes. Five sets of traffic demands are randomly generated for each test case and their average OTN equipment cost is



(a) Network 1: an American network backbone example

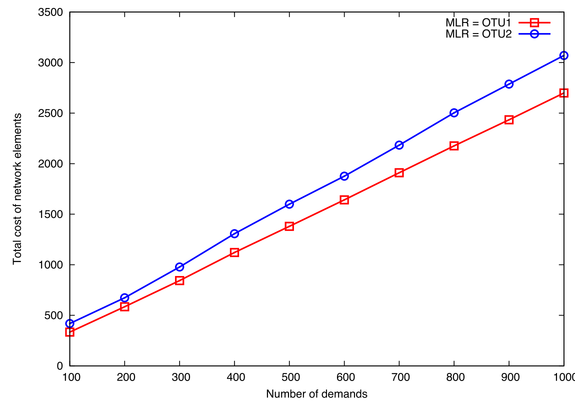


(b) Network 2: a Chinese network backbone example

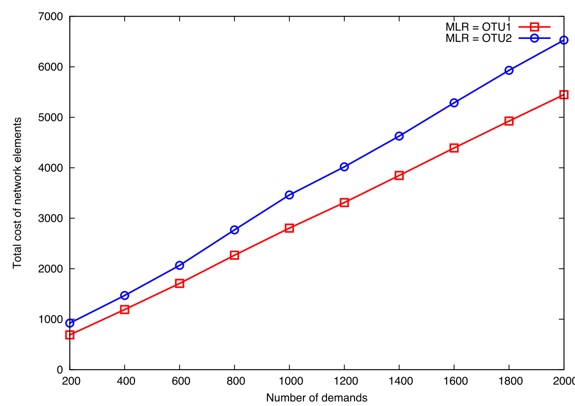
Fig. 4: Network topologies used in the experiments.

Rate (Gb)	2.5	10	40
Cost Ratio	1	2.5	6

TABLE I: Cost model of OTU line cards



(a) Network 1



(b) Network 2

Fig. 5: Results of Experiment I

computed for comparison. The cost model for the OTU line cards is shown in Table I. The experiments are run on a workstation with Intel Core 2 Q8300 (2.5 GHz) processor, 4GB memory, running Microsoft Windows 7 as the operating system.

Two experiments are considered. Experiment I tests the effect of Maximum Line Rate (MLR) — i.e., the largest line rate of the available OTU line cards — on the total equipment cost of the planned network. Experiment II tests the trade-off when choosing different values of the bandwidth threshold (THR).

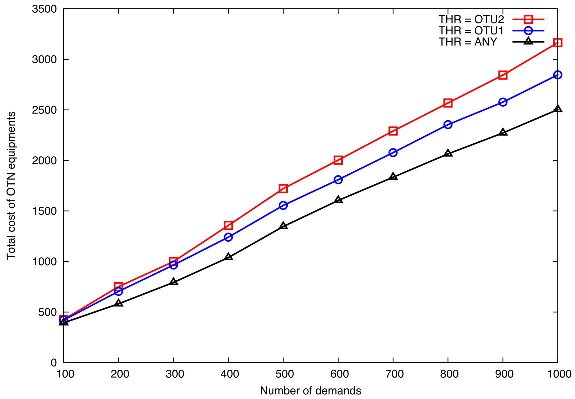
A. *Experiment I*

This experiment assumes that all required services can be wrapped into OTU1 frames, so OTU1 suffices in the network. Results obtained on both network 1 and network 2 are shown in Fig. 5. MLR can be set to be either OTU1 or OTU2. It can be seen that in all cases a higher MLR results in higher equipment costs. Although using line cards with higher MLR lower cost of line cards used for transmission, as suggested by cost model in Table I, due to technology limitation of the line cards, aggregation and disaggregation of OTU1 services require extra OTU line cards and WXCs, which increases the total cost. It can also be seen that in the larger network (network 2) the cost difference is more noticeable, as the relatively low density of services in this network (compared to network 1) makes OTU line cards with high line rate less attractive.

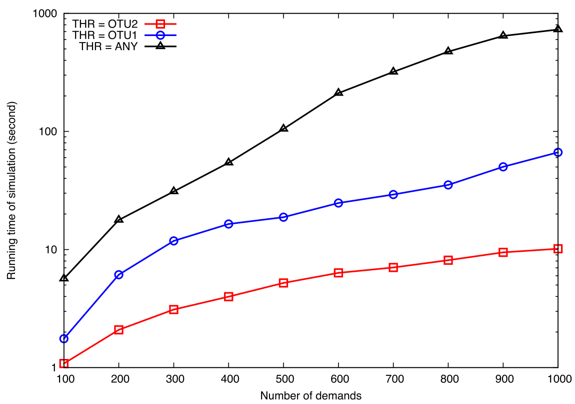
B. *Experiment II*

As already discussed in Section II-B, Step 1 of the proposed algorithm is time consuming and optional. Since each service request is considered individually, the network designer can decide which service is subject to Step 1. In this experiment, THR (the bandwidth threshold) is set to determine which group of services is subject to Step 1, with the following rationale. If the OTU wrapper corresponding to the service is below the threshold, Step 1 will not be used. For example, by setting THR to be OTU1, services that can be wrapped into ANY (Fig. 1) are not subject to Step 1. Services in this experiment consist of 50% ANY and 50% OTU1. Three thresholds are applied: ANY, OTU1, and OTU2.

Results for both networks are shown in Figs. 6 and 7, respectively. While running Step 1 gives a cost advantage, considerably longer running time is needed — a clear tradeoff between running time and total equipment cost is visible in the plots. For example, in network 1, when 1000 services need

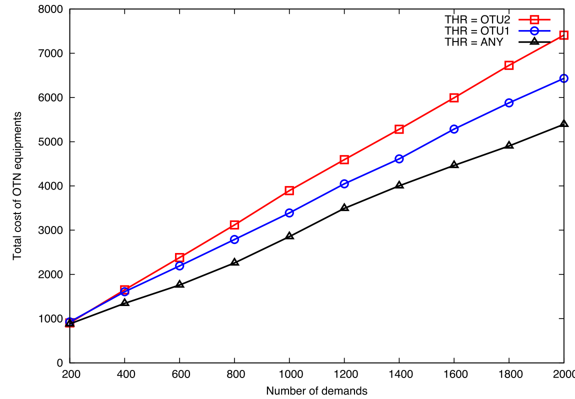


(a) Total cost of network elements vs. Number of demands

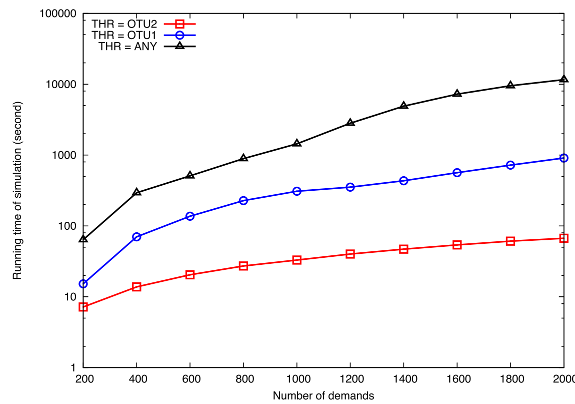


(b) Running time of simulation vs. Number of demands

Fig. 6: Results of Experiment II on Network 1



(a) Total cost of network elements vs. Number of demands



(b) Running time of simulation vs. Number of demands

Fig. 7: Results of Experiment II on Network 2

to be carried, the equipment cost when using threshold ANY is 21% lower than the cost when using threshold OTU2, while the running time of the former is about 70 times longer than the running time of the latter. Setting a lower threshold — hence using Step 1 more often — yields lower cost solutions.

IV. Summary

In this paper, the authors presented a 2-step algorithm framework for designing optical transport networks (OTNs), which provisions OTN equipment required to carry a given set of tributary services. The framework is designed to work with a general set of OTN equipment, and can be customized to account for vendor specific equipment functionalities and constraints. Another key feature of the proposed framework is the possibility for the network designer to trigger the optional step (Step 1) in the framework on a service by service basis, thus trading algorithm running time for equipment cost optimality. Experimental results for a small (24 nodes) and medium (54 nodes) size network are reported to numerically quantify the anticipated tradeoff between running time and total cost of the required OTN equipment.

While the extension of the 2-step algorithm framework to account for services that require protection switching mechanism constitutes an unresolved challenge at this time, this work appears to offer a promising direction in obtaining a common framework for cost evaluation and comparison of OTN based solutions across multiple vendor equipment platforms.

References

[1] International Telecommunication Union, “ITU-T Recommendation G.709: Interfaces for the Optical Transport Network,” International Telecommunications Union, Tech. Rep., March 2003, http://www.itu.int/rec/T-REC-G.709/en.

[2] “VPI systems,” information available at http://www.vpisystems.com.

[3] B. Chen, G. N. Rouskas, and R. Dutta, “Traffic grooming in wdm ring networks to minimize the maximum electronic port cost,” *Optical Switching and Networking*, vol. 2, no. 1, pp. 1 – 18, 2005.

[4] S. Huang, R. Dutta, and G. Rouskas, “Traffic grooming in path, star, and tree networks: complexity, bounds, and algorithms,” *Selected Areas in Communications, IEEE Journal on*, vol. 24, no. 4, p. 82, 2006.

[5] B. Chen, G. N. Rouskas, and R. Dutta, “On hierarchical traffic grooming in wdm networks,” *IEEE/ACM Trans. Netw.*, vol. 16, no. 5, pp. 1226–1238, 2008.

[6] A. N. Patel, C. Gao, J. P. Jue, X. Wang, Q. Zhang, P. Palacharla, and T. Naito, “Traffic grooming and regenerator placement in impairment-aware optical wdm networks,” in *ONDM’10: Proceedings of the 14th conference on Optical network design and modeling*. Piscataway, NJ, USA: IEEE Press, 2010, pp. 72–77.

[7] I. Chlamtac, A. Ganz, and G. Karmi, “Lightpath communications: an approach to high bandwidth optical wan’s,” *Communications, IEEE Transactions on*, vol. 40, no. 7, pp. 1171 –1182, Jul. 1992.

[8] L. Tang, S. Billenahalli, W. Huang, M. Razo, A. Sivasankaran, H. Vardhan, P. Monti, M. Tacca, and A. Fumagalli, “The planet-otn module: a double layer design tool for optical transport networks,” *11th International Conference on Transparent Optical Networks*, 2009.