The PlaNet-OTN Module: A Double Layer Design Tool for Optical Transport Networks

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ABSTRACT
PlaNet is a multilayer network planning tool designed and developed at the University of Texas at Dallas. This paper illustrates some of the features of PlaNet-OTN, one of the modules available in the PlaNet tool. PlaNet-OTN can be used to design and plan an optical transport network (OTN), which is comprised of two layers: wavelength division multiplexing (WDM) layer, which deals with wavelength allocation and routing of WDM services, and optical transport network (OTN) layer, which deals with optical data unit (ODU) equipment provisioning and routing of ODU services. Features of the PlaNet-OTN module include: multiple protection schemes and routing constraints for both WDM and ODU services, network equipment cost minimization, load balancing of traffic, and user-controlled run time of the optimization process. As shown in this paper, the PlaNet-OTN module is capable of computing service routes, allocating and configuring network equipment at both WDM and OTN layers and optimizing equipment usage, hence reducing the cost of the whole network.
Keywords: PlaNet, wavelength division multiplexing, optical transport network, network planning tool, network cost minimization.

1. INTRODUCTION

Nowadays synchronous optical networking (SONET) and synchronous digital hierarchy (SDH) technologies are still playing an important role in time division multiplexing (TDM) transport networks. Coupled with wavelength division multiplexing (WDM) technology, SONET/SDH offers a reliable and performing transport platform to many services. On the other end, traditional data networks – such as Internet Protocol (IP) and asynchronous transfer mode (ATM) – are beginning to offer alternate solutions, e.g., IP over WDM [1], [2]. Gigabit Ethernet (GE), 10GE, and 100GE interfaces are appealing options to contain transceiver cost. On one hand this proliferation of options is welcome as it can best address the multitude of today's customer requirements. On the other, it may represent a nightmare for the carrier, which must be able to service different technologies at once.

Optical transport network (OTN), defined by the ITU G.709 standard [3], provides the capability of transporting a wide variety of signals, such as fiber distributed data interface (FDDI), high-definition television (HDTV), GE, 10GE, fiber channel (FC) and synchronous transport module (STM), by wrapping them into appropriate optical data unit (ODU), and transporting them over a universal optical channel (OCh) (Fig. 1), independent of their format. OTN (a next-generation network architecture) is a network layer in which switches and routers have integrated optical interfaces and are connected directly to equipments at the optical layer, such as fibers or wavelength division multiplexers. Hence, it provides data over optics service, which can eliminate unnecessary network layers and greatly reduce cost and complexity of the whole network.

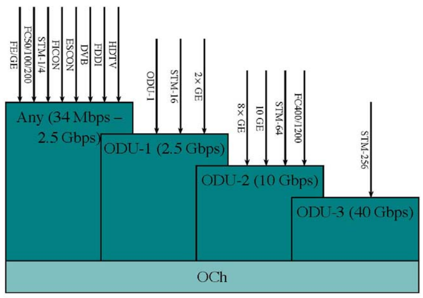

Figure 1. Signals wrapped into ODU in OTN.

PlaNet is a multilayer network planning tool recently designed, developed and extensively tested by a team that includes both graduate and undergraduate students at the University of Texas at Dallas. PlaNet is a collection of software modules that can be combined to achieve efficient design and planning of multilayer networks. Layers that can be optimized and designed with the help of PlaNet include: the physical fiber layer, the WDM layer [4], [5], the OTN layer [3], and the packet transport network (PTN) layer [6]. The tool can handle the design of both metro and core networks. This paper is focused on PlaNet-OTN, one of the modules in the PlaNet suite and a sister module of PlaNet-PTN [7]. PlaNet-OTN can be used to design and optimize both WDM and OTN layers (Fig. 2). Given physical network topology information, services or labeled switched paths (LSPs) at both WDM and OTN layers and their selected protection scheme and routing constraints, PlaNet-OTN performs the following tasks.

- Allocating and configuring WDM layer hardware, such as optical transmitters and receivers, optical amplifiers, wavelength converters, wavelength division multiplexers and cross connects.
- Allocating and configuring OTN layer hardware, such as ODU subracks, ODU cross connects, and ODU line cards.
- Computing routes for WDM LSPs (WDM layer) and ODU LSPs (OTN layer) accounting for their selected protection scheme and routing constraints.
- Assigning wavelengths accounting jointly for LSPs at both WDM and OTN layers.

The ultimate objective of PlaNet-OTN is to minimize CAPEX, i.e., the cost associated with the provisioning of all the hardware required to build both WDM and OTN layers that can support a given set of LSPs. PlaNet-OTN attempts to provide a viable solution to the network design problem by including a number of features and a modular software architecture, which easily allows for upgrades and improvements of the current feature set.

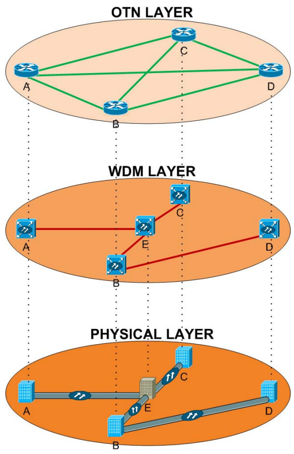

Figure 2. Multiple layers in PlaNet-OTN.

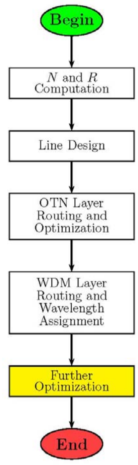

Figure 3. Flowchart of the PlaNet-OTN module.

2. DESCRIPTION OF PLANET-OTN

As shown in Fig. 3, the PlaNet-OTN module is comprised of five sub-modules:

1) *N* and *R* Computation,
2) Line Design,
3) OTN Layer Routing and Optimization,
4) WDM Layer Routing and Wavelength Assignment,
5) Further Optimization.

The five sub-modules are briefly described in the following sections.

2.1 *N* and *R* Computation

This sub-module computes the pair of values (*N*, i.e., the number of wavelengths per fiber and *R*, i.e., the transmission rate) which can best support the given set of LSPs in terms of minimizing the overall network cost. The network designer can also suggest specific values of interest for both *N* and *R* to be considered.

The computation of *N* and *R* is based on a multicommodity balanced flow algorithm applied to the entire set of LSPs, including both WDM and ODU LSPs, to make sure that sufficient resources are available in the network to sustain the desired set of LSPs. In the computation, several factors are accounted for, e.g., 1) highest transmission rate required by LSPs, 2) maximum number of fibers available in every conduit, 3) existence of parallel conduits between nodes, 4) grooming efficiency of the OTN layer, 5) utilization of the fiber wavelengths, and 6) available equipment properties. In this sub-module it is also possible to have an early detection of infeasible solutions, i.e., problems that cannot be solved unless some of the design requirements are relaxed, e.g., reduction of LSP's required bandwidth, increase of number of fibers per conduit. The output returned by this sub-module is a table, which has an entry for each pair of possible *N* and *R*, denoting the feasibility of that *N* and *R* pair and its overall expected cost. The table is passed on to the next sub-module.

2.2 Line Design

Based on the values chosen for *N* and *R*, this sub-module allocates fibers to each conduit according to the network topology and user's request (type of fibers used in each conduit may be chosen by the user). Optical amplifiers and chromatic dispersion compensation units are allocated at the WDM layer, so as to extend the propagation reach of the detectable optical signal. Physical impairment parameters such as power loss, optical signal to noise ratio (OSNR), chromatic dispersion (CD), and polarization mode dispersion (PMD) are taken into account using built-in transmission models. Additional transmission models can be plugged in, to account for other effects. The output of this sub-module is a virtual topology connecting only double layer nodes, i.e., nodes in both WDM and OTN layers (nodes A, B, C and D in Fig. 2). Nodes are directly connected in the virtual topology only if physical impairment constraints do not prevent all-optical circuits to be established between the end nodes. Multiple physical paths may be available between two nodes directly connected in the virtual topology.

2.3 OTN Layer Routing and Optimization

LSPs at the OTN layer are shown in Fig. 1. Signals with bandwidth requests below ODU-1 (2.5 Gbps), such as FDDI and STM-1/4, are classified as ANY type. GE signal, although classifiable as ANY type, having the specialty that two GE signals can be wrapped into one ODU-1, is classified individually. Signals with bandwidth requests 10 Gbps, such as 10GE and STM-64, are classified as ODU-2 type. Signals with bandwidth requests 40 Gbps, such as STM-256, are classified as ODU-3 type. LSPs are first sorted according to their types and protection schemes, with large bandwidth request and strict protection scheme having higher priority. Then LSPs are routed and their bandwidth is reserved one by one in two steps:

- **Step 1:** any spare bandwidth of OTN equipment already placed in the network is first considered for establishing the LSP. An auxiliary graph *G* is built. Each vertex in *G* represents one piece of OTN equipment that has sufficient free bandwidth to carry the LSP. Edges in *G* connect vertices whose corresponding pieces of OTN are directly connected. A shortest path in *G* is chosen as the LSP route, and the LSP's bandwidth is reserved in every OTN piece of equipment along the path.
- **Step 2:** If Step 1 fails, additional OTN equipment must be used. A shortest path is computed using the virtual topology computed by the Line Design sub-module, and adopted as the LSP route. OTN equipment is added only to every node in the virtual topology that does not already have sufficient OTN resources to handle the LSP. The LSP bandwidth is finally reserved at every OTN node along the route.

Step 1 yields network cost reduction by increasing the utilization of ODU carriers, as show in section 4.1. However, it requires more computation, especially when a large auxiliary graph is needed. Hence, this step is optional and user driven. A granularity threshold (GT) is used to indicate when Step 1 must be executed. For example, if GT is set to ODU-1, Step 1 is not applied to routing LSPs of ANY and GE type, whereas Step 1 is applied to route LSPs of ODU-1, ODU-2, and ODU-3 type. Besides the routes and OTN equipment computed for the OTN LSPs, this sub-module's output consists of a set of end-to-end OTN connections that must be routed as optical circuits at the WDM layer.

2.4 WDM Layer Routing and Wavelength Assignment

A number of optical circuits are required at the WDM layer to carry both the end-to-end OTN connections and the WDM LSPs. Their routing is computed by first applying shortest path on the graph representing the WDM nodes and conduits. Routing constraints are taken into account, e.g., including an intermediate node along the route. Routing re-optimization is then performed to accomplish one of the following objectives: *cost minimization* or *load balancing*. For example, if load balancing is selected, load of every fiber is computed individually and sorted by decreasing order. A number of optical circuits in the most loaded fiber is re-routed elsewhere if that is possible by only using already available network resources. This procedure is repeated until either the allowed run time expires or the load difference across the fibers is minimal. The run time for this optimization step is user defined.

In each conduit (group of fibers) a number of wavelength *channels* must be reserved. One channel must be reserved for every working LSP or dedicated protected LSP routed over the conduit. For the secondary paths of shared protected LSPs that are routed over the conduit, the minimum number of groups of sharing is computed (i.e., a group contains a number of LSPs that are allowed to share the protection resources). For each group of sharing, one channel is reserved on the conduit. Channels are then assigned to fibers in the conduit by a specially designed partitioning algorithm.

The last task is to minimize the number of wavelength converters (WCs) that are required in the network when all of the reserved channels for a LSP cannot be assigned the same wavelength value. The wavelength values are assigned to the LSP's channel using an approach based on both graph coloring and color popularity contest. The advantage of this approach is good scalability in terms of number of nodes, wavelengths per fiber, and optical circuits. The other advantage of the used approach is flexibility in handling all types of LSPs at once. The user can choose to stop here or go to the next sub-module.

2.5 Further Optimization

The run time of this last sub-module is user driven. A technique based on simulated annealing algorithm principles is applied to further reduce network cost by randomly attempting to remove fibers in excess and re-routing their respective WDM and ODU LSPs. Section 4.2 shows trade-off between cost reduction and run time.

3. SOME FEATURES OF PLANET-OTN

This section enumerates some of the features that PlaNet-OTN supports.

- Traffic types: PlaNet-OTN supports P2P LSPs that can be either bidirectional or unidirectional, at both WDM and OTN layers.
- Arbitrary mesh protection schemes: PlaNet-OTN supports unprotected, 1+1, 1:1, 1:N, and M:N protected LSPs at both layers. Multilayer 1:1 and M:N protection is supported for OTN LSPs. Double failure protection of type 1+1+1 and 1+1:N is supported for WDM LSPs. Disjoint type between working and protection paths can be conduit, node, and shared risk link group (SRLG).
- Ring protection schemes: custom ring protection schemes are available in ring topology, and can be combined with 1:1 or M:N protection schemes over arbitrary mesh.
- Routing constraints: when computing routes at the WDM layer, the user can request include/exclude node/conduit, disjoint working LSP pair, which can be conduit, node or SRLG disjoint.
- Multiple cores: inner core (high transmission rate, large number of wavelengths), outer core (intermediate transmission rate, medium number of wavelengths) and metro core (low transmission rate, small number of wavelengths) can be jointly optimized and combined to form one large network.
- Multiple time periods: the set of traffic requests may change over time, and the equipment can be incrementally updated.
- Operation mode: two modes are available: green field and incremental mode. In green field, new LSPs are added to a network with no pre-existing equipment. In incremental mode, new LSPs are added to a network with pre-existing equipments and LSPs.

4. EXPERIMENTS

4.1 Experiment I

The effect of GT (section 2.3) when optimizing the OTN layer is shown in Fig. 4. A network with 10 double layer nodes and 55 WDM layer nodes is used in the experiment. LSPs are comprised of 50% ODU-1 type services, 25% GE type services and 25% ANY type services. Setting the GT value to a low granularity of LSP (e.g., ANY) yields lower network cost, as Step 1 is applied to computing the route of all the LSPs at that granularity or higher. Not setting the GT value is equivalent to setting GT to a value higher than ODU-1, thus Step 1 is never used.

4.2 Experiment II

The effect of running the Further Optimization sub-module (section 2.5) is shown in Fig. 5. The same network used in Experiment I is considered. LSPs are comprised of 500 WDM LSPs and 500 ODU LSPs. The network cost is incrementally lowered by increasing the sub-module run time.

4.3 Experiment III

The run time of the flow algorithm (section 2.1) designed to include a set of intermediate nodes along the route from source to destination is shown in Fig. 6. A network with 25 nodes and 100 LSPs is used in the experiment and each LSP has 4 randomly chosen must-include nodes. Routing of LSP with must-include nodes constraint can also be achieved by K-shortest path (KSP) algorithm, possibly requiring a large value for K, which makes the procedure considerably slow and unpredictable when compared to the flow algorithm in PlaNet-OTN.

4.4 Experiment IV

A scalability and optimization test of the algorithm designed to assign wavelengths to shared protected WDM LSPs is shown in Table 1. The experiment is conducted on networks with different sizes and different numbers of WDM LSPs, all requiring shared protection M:N. PlaNet-OTN runs with up to 750 nodes and thousands of LSPs requiring only 1GB of memory. The computed number of WCs is a function of size and level of congestion in the network, i.e., almost all wavelengths in the conduits are reserved.

5. SUMMARY

This paper describes the main features of PlaNet-OTN, one of the modules available in the PlaNet tool. The module may be used to design optical transport networks, which are comprised of WDM and OTN layers, either starting from a clean state (no existing equipment in the field), or adding equipment incrementally to an already existing network. The main objective of the PlaNet-OTN module is to minimize the cost of equipment that is required in the network to support a given set of traffic demands, while taking into account a number of practical factors. The PlaNet tool was designed, developed and extensively tested by a team that includes both graduate and undergraduate students at the University of Texas at Dallas. At current time, the tool consists of about 170,000 lines of C++ code, which can be compiled and run on both Windows and Linux operating system. The challenge of designing, implementing and integrating all the features available in the PlaNet tool offered this team of students a unique opportunity to experience and understand the R&D type of environment, where loose specifications are given at the beginning of the project and must be turned into a set of concrete requirements that can be met in the limited time frame given for development.

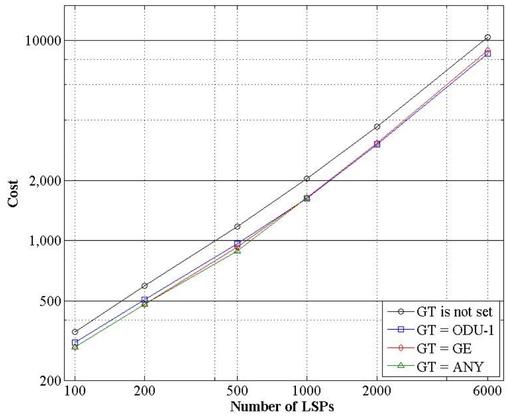

Figure 4. Effect of granularity threshold on cost.

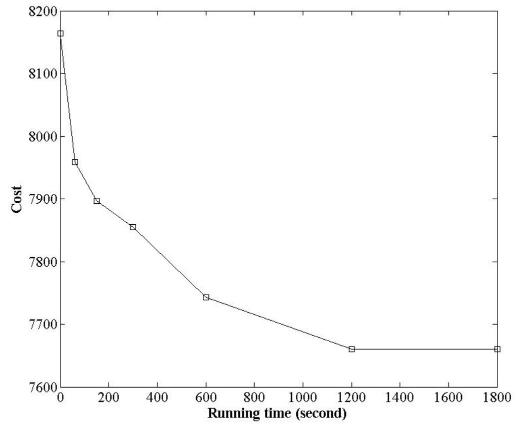

Figure 5. Effect of running time of further optimization on cost.

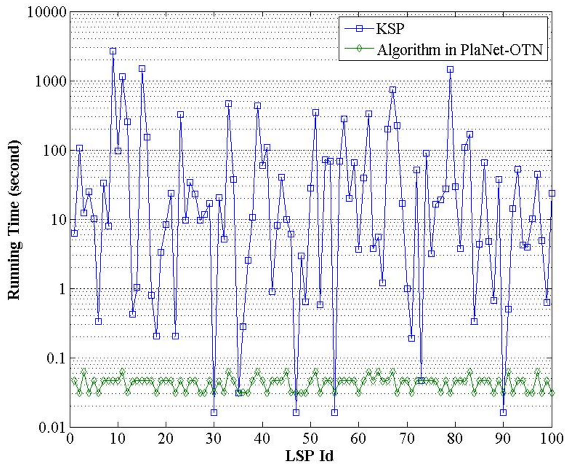

Figure 6. Running time of KSP and algorithm used in PlaNet-OTN in computing routes with multiple must-include node constraint.

N	S	L	WC	PL/Channel	T
30	133	2194	8361	5.03	99
40	179	2499	10125	5.35	135
50	223	2995	12671	5.94	201
75	335	3500	15318	6.53	267
100	446	5974	29839	7.63	855
150	666	7986	41480	8.23	1636
200	890	9998	53787	8.51	2718
300	1337	14919	86110	9.49	7199
400	1789	17989	105071	9.64	12133
500	2231	21980	132951	9.94	20155
750	3351	18000	95010	8.27	21420

N: number of nodes, **S**: number of spans, **L**: number of LSPs, **WC**: number of wavelength converters, **PL/Channel**: number of LSPs sharing a common channel, **T**: running time of the optimization.

Table 1. Scalability of PlaNet-OTN in WDM layer optimization.

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