Case study. Network planning of a multilayer IP over WDM transport network for a multi-hour traffic profile

Author:

Pablo Pavón Mariño

1   Description

This case study consists in the design of an aggregation & core network of an Internet Service Provider (ISP). The network is composed of a set of PoPs (Point of Presence) interconnected by fiber optic links, in a given topology. Net2Plan 0.5.0 planning tool is used to receive the input parameters, implement and execute the required planning algorithms. The produced design should carry the input IP traffic under three different traffic profiles, corresponding to the traffic demand estimations at three different intervals in the week.

1.1   Optical layer

The topology of PoPs is given in the file `oir2016_17ṅ2p`. The design contains two layers, named IP and WDM. The fibers are the links at the WDM layer, the IP traffic is given by the demands at the IP layer.

PoPs are interconnected by a set of unidirectional optical fibers, contracted to a dark fiber provider. The line engineering is subject to the following considerations:

- The system is designed to a maximum of 16 WDM channel in the ITU-T 100 GHz grid. Lowest wavelength is 1550.33 nm.

- Each fiber link corresponds to a G.652 fiber, with an attenuation of 0.25 dB/km, a chromatic dispersion of 6 ps/nm/km and a PMD factor equal to 0.4 ps/km$^{1/2}$.

- Optical line amplifiers can be placed, with specifications similar to that of *JDSU WaveReady Multichannel Erbium-Doped Fiber Amplifier (EDFA) WRA-219* [7]. We assume a noise factor of 5 dB in all the EDFAs, for a reference band of 0.5 nm. For each link, the potential placements where an EDFA can be put are given as input parameters of the links, as will be described later.

- Dispersion Compensation Modules (DCMs) can be placed. Their characteristics are taken from [8] but, to simplify the task, we assume that (i) dispersion compensation produced by a DCM will be constant for all wavelengths, (ii) all DCMs have the same insertion losses of 3.5 dB, and (iii) each DCM can have any compensation between -276 and -827 ps/nm.

  DCMs, when needed, should be placed in the same location of the EDFA (same position in km). When an EDFA and a DCM are collocated, we assume that the DCM is placed first (a technique targeted to decrease non-linear effects). No DCM can be placed at the initial node of the link, but they can be placed at the end node. In such case they are assumed to be before the OADM.

- The transmitter and receptor parameters are similar to that of the line cards *Cisco 1-Port 10 Gigabit Ethernet (10GE) Tunable WDM-PHY Shared Port Adapter* [4]. In the transmit side, this card integrates a transponder tunable in all the C-band. EFEC will be used. This means, in the receiver side, that there is a OSNR tolerance of 7 dB, and a chromatic dispersion tolerance of 800 ps/nm (for a receiver sensitivity range between -8 dBm and -20 dBm). The tolerance of the receiver to PMD is 10 ps, according to the values in Table 7-5 (p. 173) of [10].

- PoPs are equipped with OADMs to implement the optical add, drop and express switching of the optical channels. The scheme of an OADM of degree three is shown in Fig. 1. The characteristics of the OADMs are:

  - The OADM includes automatic power management features, that equalize the power of the added, dropped and express channels (e.g. controlling variable optical attenuators). As a result, the per-channel power of all channels (added and express) at point OADM output (point C in Fig. 1) is 6 dBm.

  - We should adjust our calculations, such that the per-channel power of all channels at OADM inputs (point A in Fig. 1) is the same. In every link this value should be equal or greater than -19 dBm.
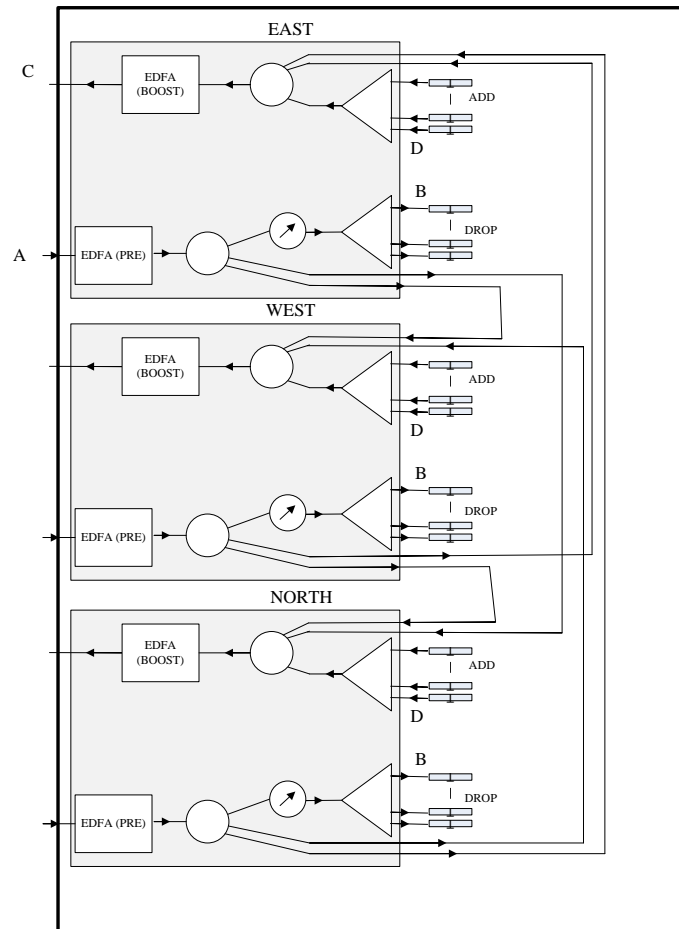
Figure 1: Diagram of 3 degree OADM.

- – We should adjust our calculations, such that the per-channel chromatic dispersion at the end of a link (including any DCM colocated at the pre-amplifier) does not exceed in absolute value 150 ps/nm. This is defined to admit a WDM channel to traverse optically at least 5 links, without exceeding the chromatic dispersion tolerance at the receiver.

- – For PMD calculations, we should consider that traversed EDFAs have similar characteristics to that of [7] (0.5 ps), and multiplexers have a PMD similar to that of [6] (0.5 ps).

- – For noise figure calculations, we assume that for add and drop channels, OADMs are seen as an element with a noise figure of 6 dB, while for express channels they are seen as an element with a noise figure of 10 dB.

- • The margins shown in Table 1 are established in each receiver, to compensate for multiple impairments. They should be considered *OSNR penalties* to substract to the OSNR at the receiver.

The students should base the line engineering in the procedure described in chapter 7, section 2 of [10].

Tabla 1: Per WDM channel margins

Impairment	optical penalty
Residual chromatic dispersion	1 dB
Self-phase modulation (SPM)	0.5 dB
Cross-phase modulation (XPM)	0.5 dB
Four-wave mixing (FWM)	0.5 dB
Stimulated Brillouin / Raman Scattering	0.5 dB
Residual Polarization Mode Dispersion	0.5 dB
Polarization Dependent Losses	0.3 dB
Transmitter chirp	0.5 dB
Mux/demux and OADMs crosstalk	0.8 dB
Unassigned margin to OSNR *penalty*	3 dB

1.2 IP layer

Offered IP traffic to be carried in the network is different at different moments of the week, because of different use patterns of the network customers. A previous study of the users' traffic has identified three representative IP traffic matrices, for three different states of the network (namely, (i) day traffic business day, (ii) night traffic business day, (iii) weekends busy hour). The file `oir2016_17.n2p` contains the information of the three traffics. In particular, for each IP demand:

- The offered traffic in the first state is the one in the `netPlan` object, returned by the merhod `getOfferedTraffic`.

- The offered traffic in the second state is stored in the attribute of name `traf2` of each IP demand.

- The offered traffic in the third state is stored in the attribute of name `traf3` of each IP demand.

The static network design to produce should have enough capacity to carry the traffic in all the three possible states.

The IP routing at the PoPs is based on IP/MPLS routers of the Cisco 12000 family. Each PoP has the following scheme:

- *Chassis*: One or more chassis, potentially of different sizes, to choose among the models Cisco 12416, 12410, 12406, 12404. Each chassis includes the switching electronics for hosting a number of line cards:

  - Cisco 12416: Can host up to 16 line cards.
  - Cisco 12410: Can host up to 10 line cards.
  - Cisco 12406: Can host up to 6 line cards.
  - Cisco 12404: Can host up to 4 line cards.

- *Line cards*: In [2] we can see a list of the line cards available for Cisco 12000 routers, together with their specifications. The ingress/egress traffic from/to network clients (*client side*) enters the PoP through 1 GbE connections. These connections enter the routers through the line cards of the type *Cisco 10-Port Gigabit Ethernet Shared Port Adapter* [5]. The traffic between PoPs (*line side*) is implemented by *Cisco 1-Port 10 Gigabit Ethernet (10GE) Tunable WDM-PHY Shared Port Adapter* [4] line cards. This line card has an integrated transponder, tunable in all the C band. If more than one chassis is needed in a PoP, they will be connected through an internal 10 GbE network. The connection of each chassis to that

internal network requires short range line cards [3]. The number of interconnection line cards needed *in each chassis*, is the maximum between the number of line cards in the line side and in the client side in that chassis.

IP routing is based on OSPF, using a single area. All the network links in the line side are assigned a weight 1. The intra-PoP links (in those PoPs with more than one chassis) are also assigned a weight of 1. Then, we guarantee that the traffic between chassis always prefers going through the direct link instead of going out of the PoP from one router, making a loop in the network, and coming back again from the other.

2   Tasks

2.1   Algorithm for PoP dimensioning: chassis and line cards

Students should implement an offline network design algorithm in `Net2Plan` tool. The algorithm will receive a multilayer network composed of two layers (e.g. coming from the output of the example multilayer network design   algorithm `OIR201617MultilayerBasicDesigner.java` executed over the problem input). The algorithm should perform the following tasks:

- For each node, create the attributes `numChassis12416`, `numChassis12410`, `numChassis12406` and `numChassis12404`, with the number of Cisco chassis of the respective type needed in the PoP according to the designed add and drop lightpaths.

- For each node, create the attributes `numClientSideCards_total`, `numLineSideCards_total`, `numIntraCnxCards_total`, with the number of client-side, line-side and interconnection cards, summing all the chassis. Naturally, in case of having a single chassis in the PoP, the attribute `numIntraCnxCards_total` equals zero.

- Recall that the values of the number of cards should be enough so that there exists a possibility to distribute the cards in the chassis, so that the number of interconnection cards in each chassis is at least equal to the maximum between the number of line and client cards in the chassis. The values produced by the students algorithm will be automatically checked, to assert that this is satisfied.

Note that the number of incoming and outgoing lightpaths in a node can be different. Then, the number of line side cards (which are bidirectional) in a PoP should be the maximum of both values. Similarly, the ingress and egress IP traffic in a node can be different, and the number of client side line cards (which are bidirectional) should be dimensioned using the maximum of both values.

The aspects to be evaluated are correctness of the result, and clarity and simplicity of the code.

Students can use the provided report `ReportPoPScheme.java` to test its code. This *report* receives as input the output of the algorithm implemented by the students, and displays information on the planned equipment.

2.2   Algorithm for WDM line engineering

Students should implement an offline network design algorithm in `Net2Plan` tool. The algorithm will receive a multilayer network design as the one in the file `oir2016_17.n2p`. The algorithm should concentrate just in the WDM layer, implementing an scheme that:

- For each link, the algorithm reads the attribute `candidateOADCMPositions_km`, with a space-separated list of positions where EDFAs and DCMs can be placed, counting as km from the link start node. Note that the file `oir2016_17.n2p` already contains this attribute.

- For each link, creates an attribute `edfaPositions_km`, with a space-separated list of the positions of the EDFA line amplifiers, which should be a subset of those in the `candidateOADCMPositions_km` attribute. EDFAs cannot be located at link end nodes: at these points the OADM booster and pre-amplifier respectively are already in place.

- For each link, creates an attribute `edfaGains_dB`, with a space-separated list of the gains (in dB) of the EDFAs placed in the link. The *i*-th element in this list is associated to the *i*-th element in the `edfaPositions_km` list. This gain is the same for all the fiber channels.

- For each link, creates an attribute `dcmPositions_km`, with a space-separated list of the positions of the DCMs in the line. Each position is given as the distance in km from the link initial node to the DCM location. These positions should be a subset of the EDFA positions, plus maybe the end node (which is not a viable position for the EDFA, but it is for the DCMs). Thus the number of DCMs placed cannot exceed the number of line EDFAs plus one. When an EDFA and a DCM are in the same location, it is always assumed that a DCM is placed right before the EDFA (a technique to reduce non-linear impairments).

- For each link, creates an attribute `dcmCDCompensation_ps_per_nm`, with a space-separated list of the chromatic compensation (negative values, in ps/nm) of the DCMs in the line. The *i*-th element in this list is associated to the *i*-th element in the `dcmPositions_km` list.

Students should make their placement algorithm considering what stated in Chapter 7, Section 2 of [10]. The aspects to be evaluated are:

- The dimensioning should guarantee that chromatic dispersion and power are within the ranges specified in the links.

- The minimum power limit at the EDFAs, should be met in the case of a fiber carrying one single WDM channel. The maximum power limits should be met even if the fiber carries 16 WDM channels.

- The Java code should be clean and clearly but sparsely documented.

- The design should include the minimum possible amount of optical amplifiers and DCMs (and thus minimum cost). Among those designs of minimum cost, the one with a better OSNR will be preferred.

To aid the implementation, the students can use the *report* `Report_WDM_lineEngineering.java` available in the `Net2Plan` repository. This report prints information about the optical signal impairments in the network. The students' design should produce a report without warnings printed for all the links and all the lightpaths in the designs produced by the `OIR201617MultilayerBasicDesigner.java` example algorithm. The report input parameter to use are the default ones, since they are the same as the characteristics of the equipment used in this case study.

2.3   Algorithm for multilayer design under multihour traffic profile

The student should develop a Net2Plan algorithm that decides the lightpaths to establish and their routes across the fibers, so that the total network cost is minimum, while all the traffic is carried in the three given traffic matrices.

The students are free to implement the IP over WDM design algorithm basing it on any optimization technique they wish. The merits of the algorithm will be assessed according to its capacity to produce designs

with lower sum of the cost in the PoPs (IP equipment). The grade will be higher, for the algorithms with better results for the values of the case study, and potentially other tests. Originality and quality of the optimization technique used, as well as code clarity will be also part of the grade.

As an example, the students are provided with the example algorithm `OIR201617MultilayerBasicDesigner.java`. This algorithm is intentionally simple:

- For each IP demand takes the largest traffic among the three traffic matrices.

- Establishes direct lightpaths between the demand end nodes, so all the traffic between these nodes can be carried through them.

Note that this scheme can be very far from optimal. The students should be able to improve their results. Some clues:

- Students should implement grooming, so some IP traffic can traverse more than one lighptath in its path to the destination. By doing so, low utilized lightpaths can be eliminated, putting its traffic in the idle capacity of other ligtpaths.

- The algorithm could attempt to consider the cost side of the lightpaths. Some lightpaths can be more expensive than others, if they mean that a larger chassis will be needed in a PoP to place it.

- The algorithm could try to exploit the knowledge of the three traffic matrices. For instance, if a set of lightpaths are used by two IP demands with opposite correlations in the traffic (when one demand has a peak, other has a valley), the total capacity needs can be reduced.

Important: The running time of the algorithm cannot exceed in any case 60 seconds. Algorithms failing to satisfy this limit (with a margin of max. 2 seconds), will be penalized.

2.4 Case study analysis

Students should generate a PDF file with an own made report that computes and analyzes different network indicators, observing their estimated evolution during five consecutive years. First year, the traffic offered is the one provided in the input traffic matrix. For the four subsequent years a 20% CAGR (Compound Annual Growth Rate) should be assumed.

Students should include the following information in the report:

- One table with the total values in each year of: (i) the number of elements included in Table 2, and its cost per element, (ii) the sum of the PoP equipment costs (including chassis, cards, and optical equipment), (iii) the sum of the operational costs (hiring costs, staff), (iv) the total sum per year.

  Note that the equipment costs the second and later years should just include the costs of the new acquisitions. Assume that the prices in Table 2 do not change along time.

- Assume that the network profits come getting paid an amount P for each carried Gbps in the network. For each of the two scenarios, calcualte the price P that makes that network investment provides an Internal Rate of Return (IRR) during the five years of 20%. The description of this analysis should include the total costs along the years, and sufficient explanations on how the price P is obtained.

- For each scenario, using the first year traffic, compute the availability of the demand with worse availability in the network, using the Net2Plan availability report, that implements the availability estimation method described in the lectures. Single and double failures should be considered.

The provisioning algorithm to use in the availability report, that implements the reaction to network failures and repair events of the IP/OSPF over WDM network, is `Online_evProc_ipOverWdm.java`, which is available in the `BuiltInExamples.jar` file integrated in the Net2Plan release. The options should be set as default, but these:

- `wdmNumFrequencySlotsPerFiber = 16`.

- The network risks to consider are one SRG per bidirectional fiber duct, considering a link availability of 99.5% (independently of its length) and a mean time to repair of 12 hours.

The evaluation will be based on the accuracy in the predicted values, the clarity in the expression and the brevity in the descriptions. The document must have a maximum length of 4 pages, not including a title page with the names of the lab group students.

Tabla 2: Network equipment costs (from [11], [14] and other sources)

Item	Unitary cost (K€)
Cisco 12416 chassis	27.5
Cisco 12410 chassis	20
Cisco 12406 chassis	18
Cisco 12404 chassis	14
Line card 10 ports 1 GbE	8.3
Line card 1 port 10 GbE (line)	7
Line card 1 port 10 GbE (interconnection)	5.2
OADM (degree 2)	20
OADM (degree >2)	40
EDFA	2.2
DCM	1
Dark fiber rent (K€/ km / year)	0.25
Personnel (year)	300

3   Evaluation

This case study should be solved in groups of two students. Exceptionally, some students can solve it individually (please, consult the lecturer first). Final grade is computed as follows:

- (15% grade) Code of the algorithm implementing PoP dimensioning (Section 2.1), for PoP dimensioning, in a Java file named `PoPEngineering_XXXX_YYYY.java`[1].

- (25% grade) Code of the algorithm implementing the WDM design (Section 2.2), in a Java file named `WDMLineEngineering_XXXX_YYYY.java`.

- (35% grade). Code of the algorithm implementing the multilayer design for multi-hour traffic (Section 2.3), in a Java file named `MultilayerMultihourDesign_XXXX_YYYY.java`, where XXXX and YYYY are the surnames of the group members.

---

[1]In all the file names, XXXX and YYYY are the surnames of the group members.

- (25% grade) PDF document with the case studio analysis (Section 2.4), in a file with name `CaseStudyAnalysis_XXXX_YYYY.pdf`.

Files should be sent by email to `pablo.pavon@upct.es`, with deadline **April 2nd, 23:00**. Delivery time will be taken from the arrival time of the email to the web server. Each hour later is penalized with one point (over 10) in the grade. Students may be asked to present their results to the class or in an interview with the teacher (this will be informed in advance).

Bibliography

[1] *Cisco 12000 Series Routers*, `http://www.cisco.com/en/US/prod/collateral/routers/ps6342/product_data_sheet0900aecd80303d86_ps167_Products_Data_Sheet.html`.

[2] *Cisco 12000 Series Routers. Data sheets*, `http://www.cisco.com/en/US/products/hw/routers/ps167/products_data_sheets_list.html`.

[3] *Cisco 1-Port 10 Gigabit Ethernet Shared Port Adapter, Version 2*, `http://www.cisco.com/en/US/prod/collateral/modules/ps6267/product_data_sheet0900aecd804dc62d_ps167_Products_Data_Sheet.html`.

[4] *Cisco 1-Port 10 Gigabit Ethernet (10GE) Tunable WDM-PHY Shared Port Adapter*, `http://www.cisco.com/en/US/prod/collateral/modules/ps6267/product_data_sheet0900aecd805fa99f.html`.

[5] *Cisco 10-Port Gigabit Ethernet Shared Port Adapter*, `http://www.cisco.com/en/US/prod/collateral/modules/ps6267/product_data_sheet0900aecd80351ee0.html`.

[6] *JDSU WaveReady 32-Channel Universal Multiplexer*, `http://www.jdsu.com/ProductLiterature/wr32cumuxds_cms_tm_ae.pdf`.

[7] *JDSU WaveReady Multichannel Erbium-Doped Fiber Amplifier (EDFA) WRA-219*, `http://www.jdsu.com/productliterature/wra219_ds_cms_tm_ae.pdf`.

[8] *JSDU WaveReady Fiber Bragg Grating Dispersion Compensation Modules WRDCMG-80TW*, `http://www.jdsu.com/ProductLiterature/WRDCMG.ds.cms.nse.tm.ae.pdf`.

[9] *Especificación Servicios de Alquiler de Fibra Oscura*, `http://www.interoute.es/sites/default/files/basic-page/file-attachments/dark_fibre_fibra_oscura_anexo_2d_version_4_2_11837.pdf`.

[10] *Optical fibres, cables and systems. ITU-T Manual 2009*, `http://www.itu.int/pub/T-HDB-OUT.10-2009-1`.

[11] *Router-Switch.com*, `http://www.router-switch.com/`.

[12] *HiSupplier.com*, `http://juneliao.en.hisupplier.com/`.

[13] *J. Zyskind, A. Srivasta, "Optically amplified WDM Networks", Academic Press 2011*.

[14] *Resolución CMT (MTZ 2011/2666).*, `http://www.cmt.es/c/document_library/get_file?uuid=b180f600-9621-4e2c-ba8d-de581f4be92a&groupId=10138#_ftn2`.