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Case study. Multi-period planning of a fault tolerant multilayer IP over WDM transport network

Author:

Pablo Pavón Mariño

1 Description

This case study consist in the design of an aggregation & core network of an Internet Service Provider (ISP), meeting fault tolerance constraints. The network is composed of a set of PoPs (Point of Presence) interconnected by fiber optic links, in a given topology. Net2Plan 0.4.0 planning tool is used to receive the input parameters, implement and execute the required planning algorithms.

1.1 Optical layer

The topology of PoPs is given in the file `oir2015_16_topology.n2p`¹. 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 0.4 dB/km, a chromatic dispersion of 15 ps/nm/km and a PMD factor equal to $0.4 \text{ ps/km}^{1/2}$.
- Optical line amplifiers can be placed, with specifications similar to that of *JDSU WaveReady Multichannel Erbium-Doped Fiber Amplifier (EDFA) WRA-219* [?]. We assume a noise factor of 5 dB in all the EDFAs, for a reference band of 0.5 nm. For placing the EDFAs along the links, it is possible to use only specific locations **situated every 10 km starting from the link end points**.
- Dispersion Compensation Modules (DCMs) can be placed. Their characteristics are taken from [?] 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. Again, 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* [?]. 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 [?].
- 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. ???. 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. ???) is 6 dBm.
 - We should adjust our calculations, such that the per-channel power of all channels at OADM inputs (point A in Fig. ???) is the same. In every link this value should be equal or greater than -19 dBm.

¹This file 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.

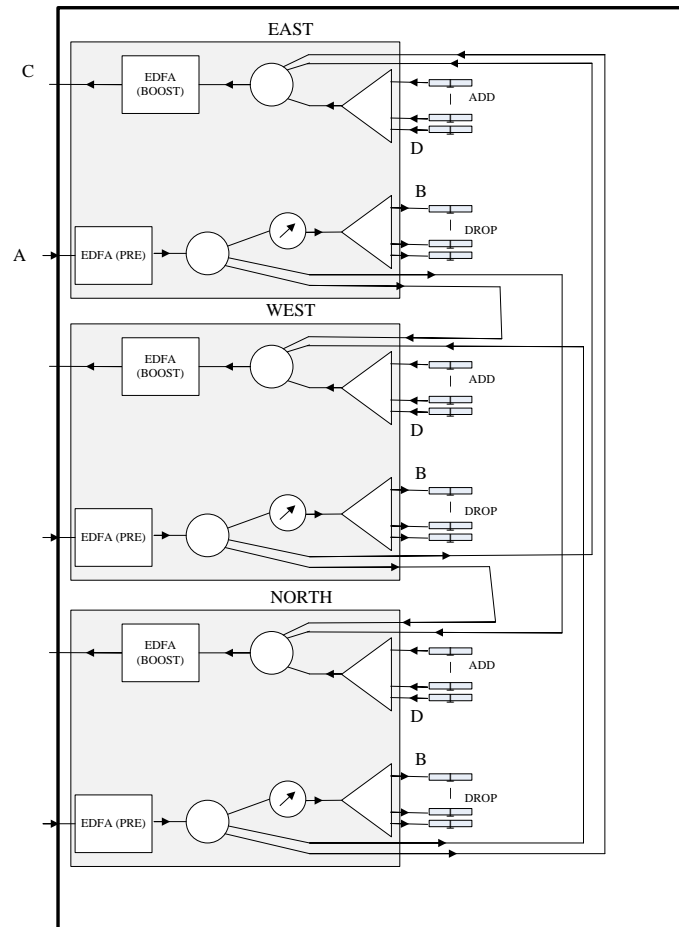


Figure 1: Diagram of 3 degree OADM.

- 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 [?] (0.5 ps), and multiplexers have a PMD similar to that of [?] (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 ?? are established in each receiver, to compensate for multiple impairments. They should be considered *OSNR penalties* to subtract to the OSNR at the receiver.

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

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 <i>penalty</i>	3 dB

1.2 IP layer

Offered traffic to be carried in the network is known, and given in the demand set of the IP layer in `oir2015_16.n2p`. 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 [?] 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* [?]. The traffic between PoPs (*line side*) is implemented by *Cisco 1-Port 10 Gigabit Ethernet (10GE) Tunable WDM-PHY Shared Port Adapter* [?] 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 [?]. 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 multi-period line card requirements

We are interested in dimensioning the network assuming the estimated network evolution during ten consecutive years. First year, the traffic offered is the one provided in the input traffic matrix. For the nine subsequent years a 20% CAGR (Compound Annual Growth Rate) should be assumed.

Students should develop a Net2Plan algorithm that receives a multilayer network composed of two layers. A WDM layer where the links are the fibers, and an upper IP layer where the demands are the offered traffic. Then, the algorithm should:

- Invoke the multilayer network design algorithm `TCFA_IPoverWDM_mixedRestoration.java` to plan the network in each of the ten years. For each year, we are interested in getting the number of client-side and line-side cards required.
- For each node, the number of NEW client-side and line-side cards needed are returned as attributes of the node:
 - Attribute `clientSideCardsPerYear` will contain the number of NEW client-side cards to acquire per year as a sequence of numbers separated by spaces.
 - Attribute `lineSideCardsPerYear` will contain the number of NEW line-side cards to acquire per year as a sequence of numbers separated by spaces.

For dimensioning the network every year, the students should use the algorithm `TCFA_IPoverWDM_mixedRestoration` executed over the given topology and traffic. The developed algorithm should have the input parameter:

- `designTolerantToSingleBidirectionalFiberCut` (default `false`). If set to true, the design should be tolerant (carry 100% of the traffic), even if a cut occurs in one duct (while the rest are undamaged), making the two fibers connecting two neighbor nodes fail simultaneously. If not, the design would just need to carry the 100% of the traffic in the no-failure situation².

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 composed of two layers. A WDM layer where the links are the fibers, and an upper IP layer where the demands are the offered traffic. The algorithm should concentrate just in the WDM layer, implementing an algorithm that:

- For each link, creates an attribute `oaPositions_km`, with a space-separated list of the positions of the EDFA line amplifiers. Each position is given as the distance in km from the link initial node to the EDFA location (**remember that it must be a multiple of 10 km**). 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 `oaGains_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 `oaPositions_km` list. This gain is the same for all the fiber channels.

²This input parameter will be just used to tune the input parameters of algorithm `TCFA_IPoverWDM_mixedRestoration.java`.

- 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. Thus the number of DCMs placed cannot exceed the number of line EDFAs plus one. 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 [?]. 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 highest traffic matrix used in this case study (10th year).

2.3 Algorithm for multi-period PoP dimensioning

The student should develop a Net2Plan algorithm that decides on the estimated acquisitions to make for the PoP equipment of the network, for the 10 years period described in the previous section. In particular, the algorithm must decide how much equipment (chassis, line cards) of each type to buy and at what time, for each node.

The algorithm will read the `clientSideCardsPerYear` and `lineSideCardsPerYear` attributes from the nodes (the ones generated by the algorithm in Section ??). Then, for each node, it will decide the acquisitions in terms of total number of NEW chassis and NEW interconnection cards to acquire, and return it in the following node attributes:

- Attribute `interconnectionCardsPerYear` will contain the number of NEW interconnection cards to acquire per year as a sequence of numbers separated by spaces.
- Attribute `numChassis12416PerYear` will contain the number of NEW chassis 12416 to acquire per year as a sequence of numbers separated by spaces.
- Attribute `numChassis12410PerYear` will contain the number of NEW chassis 12410 to acquire per year as a sequence of numbers separated by spaces.
- Attribute `numChassis12406PerYear` will contain the number of NEW chassis 12406 to acquire per year as a sequence of numbers separated by spaces.

- Attribute `numChassis12404PerYear` will contain the number of NEW chassis 12404 to acquire per year as a sequence of numbers separated by spaces.

The acquisition decisions should consider the following:

- Once an equipment is bought for a PoP (a node), it will be used for the subsequent years in the same PoP. This means that it is not possible to buy something for a PoP and then moving it later to other PoP.
- The equipment acquisition cost for the first year is given by Table ???. For the rest of the years, assume that equipment costs (chassis and line cards) decrease a 10% every year (that is, the equipment gets cheaper).
- The equipment is supposed to be bought at the start of the year. The year that an equipment is bought, its acquisition cost is included for that year. For all the subsequent years, the equipment is supposed to have operational costs (maintenance, power, cooling...) equal to a 10% of its acquisition cost.
- We are interested in the acquisition plan that minimizes the sum of the costs along the 10 years period.

Note that the multi-year acquisition plan involves a non-trivial trade-off:

- Since the prices decrease along time, there is a natural trend to delay the acquisitions as much as possible.
- Since the price-per-Gbps of large chassis is lower than the price-per-Gbps of smaller, there is a trend to buy large chassis in advance, even if they are not needed yet. Thus, this is a trend towards advancing the acquisitions.

The students are free to implement the multi-period dimensioning 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 and code clarity will be also part of the grade.

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 ten consecutive years. First year, the traffic offered is the one provided in the input traffic matrix. For the subsequent years a 20% CAGR (Compound Annual Growth Rate) should be assumed.

We are interested in comparing two scenarios:

- The network is dimensioned with the minimum capacity to carry the offered traffic if no link fails. This requires setting the option `designTolerantToSingleBidirectionalFiberCut = false` in the dimensioning algorithm.
- The network is dimensioned with the minimum capacity to carry the offered traffic if no link fails, or if a bidirectional link fails. This requires setting the option `designTolerantToSingleBidirectionalFiberCut = true` in the dimensioning algorithm.

Students should include the following information in the report:

- Two tables, one per each scenario, with the total values in each year of: (i) the number of elements included in Table ??, 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 network profits come getting paid an amount P for each carried Gbps in the network. For each of the two scenarios, calculate the price P (assumed equal along the years) that makes that network investment provides an Internal Rate of Return (IRR) during the ten 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 two forms:
 - Estimating its value from the Net2Plan availability report. Single and double failures should be considered, and the traffic in oversubscribed links should be considered as lost traffic.
 - Running a simulation with Net2Plan. The number of events to simulate is 10000, and the number of transitory events 1000. The random failure generator to use is `Online_evGen_ipOverWdm`.

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

- `ipLayerIndex = 1.`
- `ipOverWdmNetworkRecoveryType = static-lps-OSPF-rerouting` (OSPF is the one in charge of reacting to network failures).
- `wdmLayerIndex = 0.`
- `wdmNumWavelengthsPerFiber = 16.`

Students should set the input parameters, define the SRGs, MTBF etc., taking the specifications of the dark fiber contract [?] (page 10). Consider a link availability of 99.5% (independently of its length) and a mean time to repair of 12 hours. In the tests, assume a model of independent failures per SRG, exponentially distributed times to repair and to fail. This information should be printed in the report.

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 5 pages.

Tabla 2: Network equipment costs (from [?], [?] 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 Section ??, for multi-period line card requirements, in a Java file named `PoPEngineering1_XXXX_YYYY.java`, where XXXX and YYYY are the surnames of the group members. Deadline **March 18th, 23:00**.
- (25% grade) Code of the algorithm implementing the WDM design, in a java file named `WDMLineEngineering_XXXX_YYYY.java`, where XXXX and YYYY are the surnames of the group members. Deadline **March 18th, 23:00**.
- (35% grade). Code of the multi-period acquisitions plan in Section ??, with name `PoPEngineering2_XXXX_YYYY.java`, where XXXX and YYYY are the surnames of the group members. Deadline **April 11th, 23:00**.
- (25% grade) PDF document with the case studio analysis (Section ??), in a file with name `CaseStudyAnalysis_XXXX_YYYY.pdf`, where XXXX and YYYY are the surnames of the group members. Deadline **April 11th, 23:00**.

Files should be sent by email to `pablo.pavon@upct.es`. 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 of that part. 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.
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- [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.
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- [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.
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- [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.