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Case study. Multilayer IP over WDM transport network

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1 Description

This case study consist 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 0.3.0 planning tool is used to receive the input parameters, implement and execute the required planning algorithms, and to support the creation of the output reports.

1.1 Optical layer

The topology of PoPs is given in the file `oir2014_15_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.655 fiber (*Nonzero Dispersion Shifted Fiber*) of characteristics given in [9], excepting the PMD factor which should be set to 0.4 ps/km^{1/2}. Chromatic dispersion to assume is 6 ps/nm/km.
- Optical line amplifiers (EDFAs) 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 6.4 dB in all the EDFAs, for a reference band of 0.5 nm.
- 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. 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* [4]. In the transmit side, this card integrates a transponder tunable in all the C-band. We assume that all transponders transmit at an output power

¹This file contains two layers, named IP and WDM. The fibers are the links at the WDM layer.

of 3 dBm. 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 OADMs 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.
 - 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 14 dB.
- The margins shown in Table 1 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 [10].

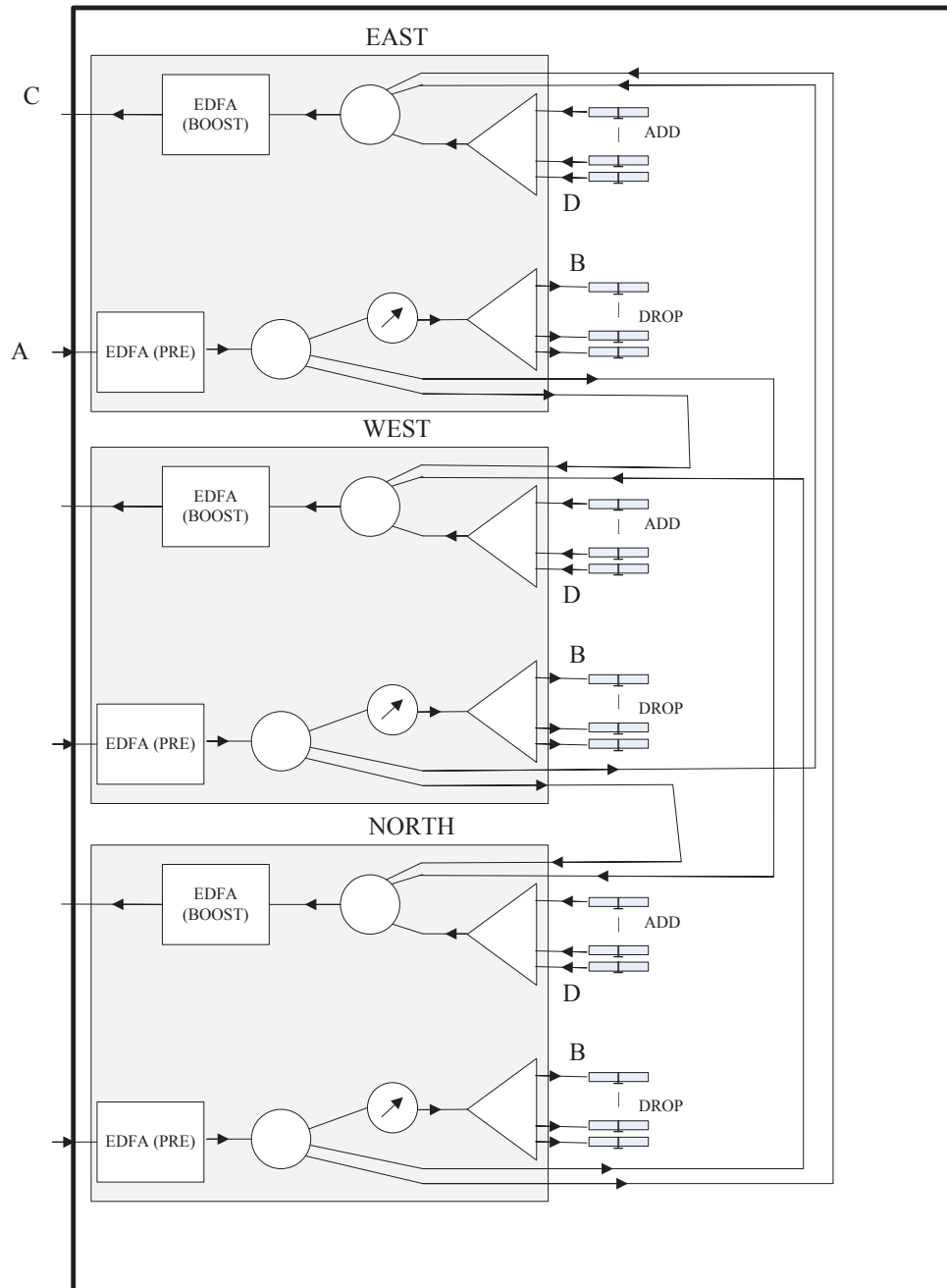


Figure 1: Diagram of 3 degree OADM.

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 traffic matrix $\text{oir}_{2014_15_tm_1.n2p^2}$. The IP routing at the PoPs is based on IP/MPLS routers Cisco 12000 (12416 model). Each PoP has the following scheme:

- *Chassis*: One or more chassis Cisco 12416 (including the switching electronics in the chassis), where the line cards are hosted. Each chassis has a capacity of 16 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.

²Recall that to add these demands as offered traffic to the IP layer in our multilayer design, the matrix should be loaded when the IP layer (and not the WDM layer) is the active one in the graphical user interface.

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

Students should implement an offline network design algorithm in `Net2Plan` tool. The algorithm will receive a multilayer network composed of two layers, coming from the output of the multilayer network design algorithm `TCFA_IPoverWDM_mixedRestoration.java` executed over the given topology and traffic. The algorithm should perform the following tasks:

- For each node, create the attribute `numChassis`, with the number of Cisco 12416 chassis 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.

Note that the number of incoming at outgoing lightpaths in a node can be different. Then, the number of line side line cards (which are bidirectional) should be dimensioned using 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 generates 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 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 `edfaPositions_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. 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. 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 [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.

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. For getting the maximum grade, the students design should produce a report without warnings printed, for all the links and all the lightpaths in the highest traffic matrix (5th year).

2.3 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.

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 `dimensionForSingleSRGFailure = 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 `dimensionForSingleSRGFailure = true` in the dimensioning algorithm, and configuring the SRGs accordingly in the input design. This latter step can be automated by setting `setSRGsAsBidirectionalLinkFiber` to `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 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, calculate 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 two forms:
 - Estimating its value from the Net2Plan availability report. Single and double failures should be considered.
 - 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 `NRSim_EG_exponentialSRGFailureGenerator`.

In both cases, the provisioning algorithm to use, that reacts to network failures and repair events as OSPF layer does, is `NRSim_AA_IPoverWDM_mixedRestoration.java`, which is available in the `BuiltInExamples.jar` file integrated in the Net2Plan release. The option `isLpRestorationActivated` should be disabled, since in our case study the IP layer is the only one reacting to failures (lightpaths are no restored as a reaction to failures, just OSPF reroutes the to avoid failing lightpaths). In both evaluations, the options `allowLinkOverSubscription` and `assumeOverSubscribedLinksAsFailedLinks` should be active, such that all the traffic traversing a link with an utilization higher than 100%, should be considered lost. Students should set the input parameters, define the SRGs, MTBF etc., taking the specifications of the dark fiber contract [9] (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 [11], [14] and other sources)

Item	Unitary cost (K€)
Cisco 12416 chassis	27.5
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)	0.40
Rent and maintenance of PoPs (year / PoP)	10
Personnel (year)	300

2.4 Enhancement of the dimensioning algorithm

The students are challenged to enhance the dimensioning algorithm provided `TCFA_IPoverWDM_ospfRestoration.java`, that determines the lightpaths to establish in the network, their routes and the IP routing that carries all the offered traffic. For the sake of simplicity, only the case where single failure SRG is *not* considered should be addressed.

The new algorithm can decide the lightpaths to establish in a different form, and has an extra degree of freedom to jointly decide other OSPF weights for the links (as long as they are integer numbers between one and ten). The students can base their algorithm on any optimization technique they wish (e.g. an application-specific heuristic, simulated annealing, genetic algorithms, tabu search GRASP, ...). Documentation on these methods will be provided.

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 traffics and topologies 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 algorithm developed must include an input parameter called `maxSimulationTimeInSeconds`, with default value 120 (two minutes). This is the maximum running time allowed to the algorithm. The implementation must return the best solution found so far when this limit is reached. Algorithms failing to satisfy this limit (with a margin of max. 2 seconds), will be penalized.

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:

- (10% grade) Code of the algorithm implementing the PoPs dimensioning, in a Java file named `PopEngineering_XXXX_YYYY.java`, where XXXX and YYYY are the surnames of the group members. Deadline **March 9th, 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 23rd, 23:00**.
- (50% grade) PDF document with the case studio analysis, in a file with name `CaseStudyAnalysis_XXXX_YYYY.pdf`, where XXXX and YYYY are the surnames of the group members. Deadline **April 13th, 23:00**.
- (40% grade, yup, this sums up more than 100%). Code of the dimensioning algorithm with name `TCFA_OIR_XXXX_YYYY.java`, where XXXX and YYYY are the surnames of the group members. Deadline **April 8th, 23:00**. Students will be asked to present their algorithm to the class in a presentation on April 13th, 15:00 (max 5-6 minutes per algorithm).

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 can be subject to a personal interview for evaluating the case study.

References

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