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Case study. Network planning, cost and upgrade analysis in a multilayer IP over WDM transport network

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1 Description

This case study consists in the design and analysis 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 planning tool is used to visualize, plan and analyze the multilayer network in this use case.

1.1 Lab groups and year-0 n2p file

Lab groups will be formed, with two students per group. Groups will be created during the first lab session. Exceptionally, groups of one person will be allowed, under request.

Each group will have assigned a number 0, 1, 2, The i -th group will be assigned the file `oir201819_group_i.n2p`. This file contains a multilayer network to plan, with the topology of PoPs and WDM links between them, as well as the IP traffic in the year 0.

1.2 Optical layer

The multilayer design contains two layers, named `IP` and `WDM` in the Net2Plan file. 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 channels in the ITU-T 50GHz grid.
- 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 $0.4 \text{ ps/km}^{1/2}$.
- Optical line amplifiers, of EDFA type, will be placed. Students will have to determine the number of them in each WDM link. Maximum EDFA gain to consider is 23 dB.
- No Dispersion Compensation Modules (DCMs) are placed.
- 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.
 - In every link, the received power at point A in Fig. 1, should be equal or greater than -19 dBm.

1.3 IP layer

The `n2p` file of each group will contain the IP demands offered to the network in year 0. The static network design to produce should have enough capacity to carry the traffic.

The IP routing at the PoPs is based on modular IP/MPLS routers, consisting on **one** IP chassis per PoP, containing each of them one or more **line cards**, where each line card can contain a number of IP ports.

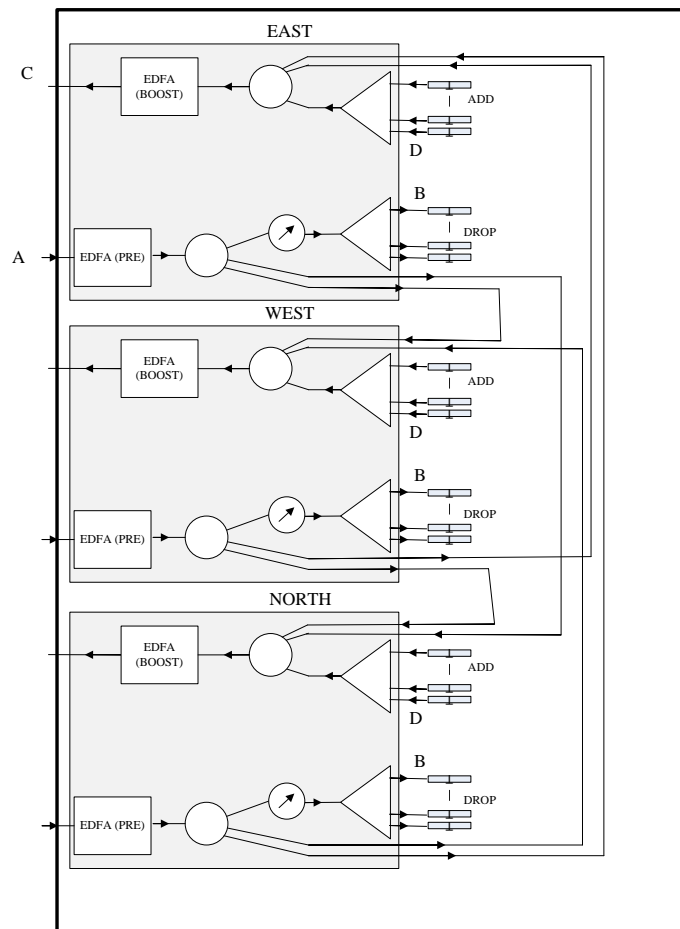


Figure 1: Diagram of 3 degree OADM.

- *Chassis*: Exactly one chassis per PoP. Each chassis includes the switching electronics for hosting a number of line cards:
 - Model M40: Can host up to 40 line cards.
 - Model M20: Can host up to 20 line cards.
 - Model M10: Can host up to 10 line cards.
 - Model M4: Can host up to 4 line cards.
- *IP Line cards*: Each line card occupies one slot in the node chassis, and has an overall throughput of 100 Gbps. Two types of line cards exist:
 - *Client-LC*: Has room to attach up to 10 IP ports of 10 GbE each. This is expected to receive the client traffic that eventually should be sent though the transport network.
 - *Line-LC*: Has room to attach one 100G IP port.
- *IP port*. An IP port is a module that is plugged in the line card. We consider two types of IP ports:
 - Client 10GbE IP ports. They can be plugged to Client LCs. Recall that one client LC can host up to ten 10 GbE ports.
 - Line side 100 GbE port. This port fully occupies one line card.

IP routing is based on OSPF, using a single area. All the network links in the line side are assigned a weight 1.

2 Tasks

2.1 Algorithm for PoP and WDM dimensioning

Students should implement an offline network design algorithm in `Net2Plan` tool. The algorithm will receive a multilayer network like the one assigned to each group in the `n2p` file.

The algorithm should complete the following actions:

- Call the method `plan` of the class `ToStudents_ipOverWdmPlanningAlgorithm` provided to the students. This algorithm:
 1. Removes any existing IP links and lightpaths in the design.
 2. Creates the required IP links and lightpaths so the traffic is satisfied, using the lightpaths of the given line rate, with the given maximum number of lightpaths per fiber, and **with** the request that the design should be fault tolerant.

When fault tolerance is requested, the design will tolerate that all the WDM links between two nodes fail, for all the pairs of nodes in the network. Note that in this use case, when WDM links fail, the lightpaths traversing them also fail, but traversing IP traffic can survive thanks to OSPF reaction.

- Calculate for each node, the number of client 10 GbE ports as the minimum number of ports needed for handling input/output traffic from the client side¹. The number of client 10 GbE ports is returned in the node attribute `numClientPorts10GBE` (use the method `setAttribute`).

¹Note that this applies to the *maximum* between the traffic of IP demands (i) initiated and (ii) ended in the node. Such demands can be obtained with the methods `getIncomingDemands` and `getOutgoingDemands` in the `Node` class, for the IP layer.

- Calculate for each node, the number of line 100GbE ports, as the maximum between the number of lightpaths initiated in the node, and the number of lightpaths ended in the node². The number of line 100 GbE ports is returned in the node attribute `numLinePorts100GBE` (use the method `setAttribute`).
- Calculate for each node the number of Client-LC line cards and the number of Line-LC. These numbers must be returned in the attributes `numClientLC` and `numLineLC` respectively.
- Calculate for each node the chassis required, as the smallest needed according to the number of line cards. The number of slots of the chassis to be selected (40, 20, 10, 4) should be returned in the node attribute `numSlotsChassis`.
- Calculate, for each WDM link, the *minimum* number of line EDFAs required, so the optical signal has enough power at the end of the WDM link. There is no need to calculate the positions of the EDFAs. The number of EDFAs in each WDM link, should be returned in the link attribute `numEdfas`.

The aspects to be evaluated are:

- The correctness of the results.
- The Java code should be clean and clearly but sparsely documented.

To aid the implementation, the students can use the *report* `ToStudents_checkReport.java` provided. This report prints information of the attributes of the nodes and links described above, so the results produced by the algorithm can be visualized.

2.2 Case study analysis report

Students should generate a PDF file with the following information:

5-year cost analysis

This analysis should permit understanding how the cost will evolve from year 0 (now), to year 5. The report should assume that IP traffic in year 0 is the one in `n2p` file provided. Then, traffic in each IP demand grows with a CAGR (*Compound Annual Growth Rate*) of 25%. That is, the traffic in year $i = \{1, 2, 3, 4, 5\}$ is 1.25^i times the traffic in year 0.

This section should include a table with one row for each type of element in the network subject to have cost (i.e. one row, for each row in Table 1), plus one row with the aggregated figures summing the rows above. The table should have two columns for year 0, two columns for year 1,..., and two columns for year 5. The two columns of each year are the number of NEW elements to be acquired that year for each type, and the cost associated to those acquisitions (that is, unitary cost multiplied by the number of units).

Note: The equipment costs in years after year 0, should just include the costs of the **new** acquisitions. However, note that the operational costs (personnel, fiber rent) are incurred every year.

Note: Assume that the prices in Table 1 do not change along time.

Note: The decision of the chassis to acquire for each PoP should be made considering the traffic **in the last year**. That is, each node should have the cheapest chassis according to what will be needed at year 5, and not the needs at the year 0.

²Use the method `getIncomingLinks` and `getOutgoingLinks` in the `Node` class, for the IP layer, to get these lightpaths

Price analysis

Assume that the network profits come getting paid an amount P for each carried Gbps in the network. According to this, the cost analysis section should report the price P that makes that network investment provide an Internal Rate of Return (IRR) from year 0 to 5 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.

WDM plant upgrade analysis

We are interested in analyzing when (in which year) the WDM plant of the network will **not** have enough capacity for carrying the IP traffic demand, assuming a CAGR of 25%. Note that this will happen when WDM fibers, that are limited to 16 channels, cannot carry the required lightpaths.

Let us call **upgrade year**, to such first year when the WDM plant will **not** be enough.

This section should include:

- An indication of the upgrade year for the network as it is.
- A table with one row for each node pair $\text{Node1} - \text{Node2}$ in the network, where Node1 is different to Node2 ³. The table should have two columns, (i) one indicating the upgrade year IF the network had two more WDM links ($\text{Node1} \rightarrow \text{Node2}$ and $\text{Node2} \rightarrow \text{Node1}$), and (ii) other indicating the per year total dark fiber renting cost for that node pair, summing both WDM links.

According to this, briefly discuss which node pair would you use to upgrade the WDM plant and why.

Tabla 1: Network equipment costs

Item	Unitary cost (K€)
Chassis Model M40	50
Chassis Model M20	32
Chassis Model M10	20
Chassis Model M4	14
(Client) Line card 10x10 GbE	10
(Client) Pluggable port 10 GbE	0.5
(Line) Line card 1x100 GbE	9
(Line) Pluggable port & 100 GbE	25
OADM (degree 2)	20
OADM (degree >2)	40
EDFA	2.2
Dark fiber rent (K€/ km / year)	0.20
Personnel (year)	300

³In addition, pairs $\text{Node1} - \text{Node2}$ and $\text{Node2} - \text{Node1}$ should be considered as the same pair, and thus only one of both should be included

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:

- (30% grade) Evaluation of the algorithm in Section 2.1. This part must be delivered as one single Java file named `q1_XXXX_YYYY.java`⁴ implementing the Net2Plan algorithm. The algorithm should not have any input parameter (or just consider that it will be tested with the default parameters there).
- (70% grade) Evaluation of the case study analysis report described in Section 2.2. The students can deliver this part in one out of two possible forms (one or the other, not both):
 - As a PDF file, named `q2_XXXX_YYYY.pdf`. 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 3 pages, not including a title page with the names of the lab group students. The maximum grade for groups delivering the report in this form is 50% (and thus, the maximum reachable grade of the use case is 80%).
 - As a Java file implementing a Net2Plan report with name `q2_XXXX_YYYY.java`. The report should produce an HTML file with the tables, and brief discussions requested. Normal HTML formatting, structuring things into sections, is enough. No need of fancy designs (note that Net2Plan HTML viewer is quite simple). The groups delivering the report in this form with correct values can achieve the full grade 70% (and thus, the maximum reachable grade of the use case is 100%). The report will be tested with the default parameters it has, if any.

Files should be sent by email to `pablo.pavon@upct.es`, with deadline **June 3rd, 19:00**. Delivery time will be taken from the arrival time of the email to the web server. Each hour late is penalized with one point (over 10) in the grade. Students may be asked to present their results in an interview with the teacher.

The Java code and reports from the students will be scrutinized by the lecturer, and automatically validated and compared by a software comparator, to detect copies of the content / code, between groups. Please be advised that, according to current UPCT regulations, any infraction in this sense implies a zero (0) in the global final grade of the course.

⁴In all the file names, XXXX and YYYY are the surnames of the group members.

Bibliography

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- [4] *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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- [6] *Resolución CMT (MTZ 2011/2666)*, http://www.cmt.es/c/document_library/get_file?uuid=b180f600-9621-4e2c-ba8d-de581f4be92a&groupId=10138#_ftn2.