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Lab work #2. IP over WDM with Net2Plan NIW framework

(1 session)

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1 Objectives

The existence of multilayer IP over WDM networks stems from the technological fact that is much cheaper to e.g. optically switch 100 Gbps in an OADM, than to IP route it in the IP layer, incurring in extra transponder and IP line card costs.

The goals of this lab work are:

1. Cover basic concepts related to multilayer IP over WDM networks.

2. Introduce the use of the NIW framework of Net2Plan, and its graphical user interface, for analyzing and planning of IP over WDM networks.

In further lab works we will concentrate in other aspects of multilayer networks.

2 Duration

This lab work is designed for one session of two hours.

3 Evaluation

This lab work has been designed to guide the students in their learning of the subject. The annotations the students make in this document are for their use when studying the course, and do not have to be delivered to the teacher for evaluation.

4 Documentation

The resources needed for this lab work are:

- Lecture notes of the course.
- Net2Plan tool and their documentation (see `http://www.net2plan.com/`).
- Instructions in this wording.

5 Previous work before coming to the lab

- Read lecture notes related to IP over WDM networks.
- Install last Net2Plan version in `https://github.com/girtel/Net2Plan/releases`

6 Creating a WDM topology

6.1 Creating the WDM plant

Follow the next steps to create an WDM topology:

- Activate the NIW framework in Net2Plan main window by clicking the `NIW` button. Also, in the `What-if analysis`, activate the what-if analysis mode (expand the window to find it). In this form, the design is automatically updated to reflect manual changes made in the graphical interface (e.g. when setting links as down, the traffic losses are automatically updated).

- Create an empty design, with an empty IP and WDM layer, clicking the `Reset button`.

- In the `View/edit network state` tab, and `Network` subtab, you will find a table with one row per layer: IP and WDM (note that `NIW` option must be activated). Since we are interested in this section just in the WDM layer, select the IP layer in the table, and remove it by using the appropriate right-click menu option.

- In the geographical view (click on the `Site` icon to show the map), add five nodes to the design, placing them approximately in the following cities of Spain: Madrid, Barcelona, Cartagena, Sevilla and Ourense. Then, add a ring WDM topology, with *bidirectional* WDM links as shown in Fig. 1. For adding a new bidirectional WDM link, click the origin node, with SHIFT key pressed, and drag the mouse to the other node[1]. Which is the total number of kms of fiber? Which is the length of the longest link?

- Which is the default usable spectrum in each WDM fiber (minimum and maximum frequency)? Which ITU band this corresponds to?

- In the `OADMs` table (again, `NIW` framework must be active for this table to appear), set the node names to the one of their cities, and the populations of the nodes to: Madrid 3273, Barcelona 1619, Sevilla 704, Cartagena 214, Ourense 108 (all numbers are measured in thousands of inhabitants).

- Save the topology with the name `topWdm.n2p`.

6.2   Adding lightpaths

Follow the next steps:

- Add a bidirectional lightpath request to the design, from Madrid to Cartagena, requesting a line rate of 100 Gbps, that should be 1+1 protected. Use the right-click option `Add lightpath request` in the `Lightpath requests` table. Is the lighptath request carried?

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[1]In general, the link lengths are set to the geographical distance by default. If not, you have to select all the links and use the appropriate right-click option in the `Fibers` table
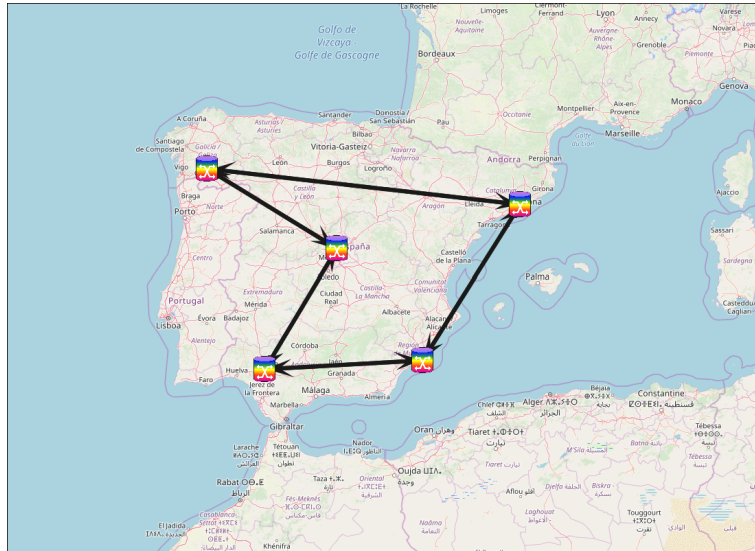
Figure 1: WDM topology (bidirectional links).

- Add a bidirectional lightpath request to the design, from Barcelona to Sevilla, for a line rate of 100 Gbps, but *not* 1+1 protected. Is the lighptath request carried?

- Select the lightpath requests created. Use the right-click option `Add lightpath to selected requests`, to add the lightpaths that realize these requests. All lightpaths should occupy 50 GHz (4 slots of 12.5 GHz), and their route should be computed to minimize the optical latency. Leave the other options with their default values. How many lightpaths are assigned to 1+1 protected requests? Are they fiber disjoint? Which are the two paths? In the 1+1 requests, which is the value assigned to the worst end-to-end length and latency?

- In the `Fibers` table, set as down the fiber between Cartagena and Barcelona, in both directions. How many lightpaths are down? Is it down the lightpath request from Cartagena to Madrid? why? and the one from Barcelona to Sevilla?

- Set all the fibers up again. In the `Lightpaths` table: Which are the optical slots occupied by the lightpaths? Why some lightpaths occupy different slots?

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- Use the option `Set optical slots occupied to selected lightpaths`, and make the light-path from Barcelona to Sevilla (unidirectional) to occupy the slots 3, 4, 5, 6. Is this change affecting other lightpaths? how? why?

- In the `View reports` tab, run the routing spectrum and modulation assignment report:

  `ReportNiw_wdm_routingSpectrumAndModulationAssignments`

  Observe the information there. Is the wavelength clashing information also visible in the report?

7 Creating an IP topology

In this section, we create and manipulate an IP over WDM topology, to exemplify this type of networks.

Follow the next steps:

- Load the `topWdm.n2p` topology. Remind to turn on the NIW mode and the what-if analysis mode, if not active. **Remove all the lightpath requests in there** (which will also remove the associated lightpaths).

- Add an IP layer to the model. For this, in the `Network` tab, `Layer information` table, use the right-click option `Add IP layer`. See that one more layer is now shown in the topology panel.

- See the controls at the left part of the topology panel that permit: (i) making a layer visible or not (single-click its name), (ii) making a layer the main layer in the design (double-click its name), (iii) showing each layer in an upper or lower position (clicking the triangle arrows). Use these controls to place the IP layer at the top, and also making it the IP layer the active layer, by double clicking on `IP`. Now, IP icons are printed larger, and if a link is added in the topology panel by clicking and dragging between two nodes, a bidirectional IP link is created (and not a WDM fiber as before) .

- How many routers are there in the design? Is there one router for OADM? How many IP links do we have? How many WDM fibers? (check the topology panel and the `OADMs`, `IP routers`, `IP links` and `Fibers` tables)

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- Create one unicast IP demand between each node pair, using the appropriate right-click option in the `IP demands` table. The demands should be all routed using OSPF (hop-by-hop routing). How many demands are created? which is the total offered traffic?

- Select all the IP demands, and set its offered traffic, so the traffic of each IP demand is proportional to the sum of end node populations, and the total traffic sums 1 Tbps (1000 Gbps). For this, use the appropriate right-click option in the `IP demands` table. Is the IP traffic carried? why?

- In the topology panel, create a star IP topology, with one IP link (bidirectional) between Madrid, and each of the other nodes (so a total of 8 unidirectional IP links are created). Which is the default capacity assigned to all the links? Is all the IP traffic of the demands carried? Are there oversubscribed IP links (links with QoS violation, in particular in this case, with more carried traffic than capacity)? Paste a screenshot of the topology panel.

- We are interested in dimensioning the IP link capacities, so each IP link has a maximum utilization of 90%, and its capacity is a multiple of 100 Gbps. The capacity in the IP link must be the same in both directions. Use the right-click option `Set selected links capacity -> to match given utilization` for this purpose. Which is the total amount of capacity to be installed in the IP links? Is all the traffic carried now, without oversubscription? which is the maximum utilization among all the IP links? which is the average number of IP hops in the network? (see the IP layer `General` tab, `Routing` performances in the table above the `Focus panel`)

- We want to realize each IP link, as a Link Aggregation Group (LAG) with the same capacity, where each LAG aggregates enough IP links of 100 Gbps to match the required capacity. In the `IP links` table, use the `Link Aggregation Group (LAG) options -> Convert selected links into LAGs...` for realizing this. How many LAG members are newly created? (see the IP links that are LAG members in the `IP links` table)

- Change the IGP weight in the Madrid to Cartagena link, making it equal to 10. Is there any change in the IP routing? why? set back the IGP weight to one.

- Save current design as `topIp.n2p`.

8 Creating the IP over WDM design

In this section, we extend the IP design created in the previous section, adding the lightpaths in the lower layer that realize the IP members created[2].

Follow the next steps:

- First, we associate (couple) each IP link member, to a newly created lightpath request, that will be later realized through a lightpath. To do this, use the `IP links` table right-click option `Create & couple lightpath requests for uncoupled selected links`, after selecting all the IP links. How many lightpath requests were created? Are the lightpath request associated to the IP bundles?

See that the **current** capacity of all the IP LAG members is equal to zero now, while their nominal capacities are the same as before. This is because they are coupled to a lightpath request, and

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[2]Note that at this moment, since the IP links are not realized by any underlying lightpath, its length has a default value (1 km).

its previous nominal capacity value is no longer the current one. Its current capacity is zero since the lightpath requests associated are not realized by any lightpath yet. If they are, and the lightpath is up, the IP link current capacity will be equal to the lightpath line rate.

Similarly, the capacities of the LAGs is zero, since it is the sum of the current capacities of the LAG members.

- Assert that all the lightpath requests *do not* require being 1+1 protected.

- Realize all the lightpath requests setting up the lightpaths, using the shortest path in optical latency, and using 4 optical slots (50 GHz) of occupation for each lightpath, and not using directionless ADD/DROP modules[3]. For this, use the appropriate right-click option in the `Lightpath requests` table. Are all IP links up and with its current capacity equal to its nominal capacity? Is all the IP traffic being carried without oversubscription?

- Analyze the IP path and the WDM path of the traffic of the IP demand from Barcelona to Ourense. Which are the IP links traversed?[4] Which is the WDM path of each IP link for that demand[5]? Has the total WDM path any cycles? Which is the end-to-end latency and total WDM length in km of the IP demand?

- Which one is the IP demand with highest end-to-end latency? Are their nodes directly connected by a fiber? where all this latency comes from?

The student should explore the routing, and observe and make him/herself familiar with some facts in multilayer networks:

- IP demands are routed by the IP layer according to the IP routing policy configured (e.g. OSPF ECMP routing in our examples).

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[3]Directionless ADD/DROP modules are modules installed in the OADMs to add and drop lightpaths starting and ending there. If a transponder is attached to a directionless module, its possible to change its direction (the first (in add) or last (in drop) fiber traversed) remotely. Instead, directionful modules are directly attached to the in/out fiber of the OADM. If a transponder is placed there, we are fixing its first/last fiber to traverse (its direction). To change the lightpath duraction, a technicial would have to manually reattach the transponder to other module.

[4]This can be observed in the topology panel, that highlights the IP path when clicking the demand, or in the appropriate column in the `IP demands` table.

[5]This can be observed in the topology panel, that highlights the WDM path when clicking the IP link, or in the appropriate column in the `Lightpath` table.

- The optical circuits or lightpaths are the physical form in which IP links are realized in the transport. Each lightpath occupies a particular spectrum in the traversed fibers. If two lightpaths have overlapped spectrum, they cannot have traversed fibers in common. If they do, it is called wavelength or spectrum clashing, and optical signal becomes undetectable at the receiver end of affected lightpaths.

- Concatenating the WDM paths of each traversed IP link, we can find that some IP traffic can make cycles when propagating through the fibers. This is because: (i) the IP traffic is routed through the shortest path of IP links (loopless at the IP layer), and (ii) each IP link is realized by lightpaths routed through the shortest path across the fibers (loopless at the WDM layer), BUT (iii) the *concatenation* of those WDM shortest paths, is path that can have arbitrary cycles.

- There are multiple implications in terms of cost and performance of a single change in the IP or WDM layer like adding a new IP link. For this reason multilayer design requires from specialized software, with appropriate design algorithms. In future lab works we will explore some of the multiple trade-offs and involved implications appearing in multilayer design.

Quiz 1. Repeat the IP over WDM topology using 1+1 lightpaths. Note the effect in the worst case latencies and lengths at the IP layer.

Quiz 2. Repeat the IP over WDM topology using a full-mesh topology of IP links. Compare the total amount of WDM transponders required (number of lightpaths), with respect to the original design, where the IP topology was a star[6]. Make the comparison using unprotected and 1+1 protected lightpaths.

9   Work at home after the lab work

The student is encouraged to complete all the tasks that he/she could not finish during the lab session, and the Quizs proposed.

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[6]Since transponders and associated IP line cards attached to them, are one of the most expensive elements in the IP over WDM network, they are often used to compare the cost among different alternatives