WDM networks planning under multi-hour traffic demand with the MatPlanWDM tool

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ABSTRACT
MatPlanWDM is a MATLAB-based publicly available network planning tool for Wavelength-Routing (WR) optical networks, and it was fully developed by our research group. This paper describes the multi-hour planning analysis extension included into the MatPlanWDM version 3. This novel functionality allows the user to test planning algorithms which react under changes in the traffic demands. Multi-hour traffic patterns appear typically in backbone WR networks that span over large geographical areas, where network nodes are situated in different time zones. A case study example is included to illustrate the merits of the tool.

Categories and Subject Descriptors
G.4 [**MATLAB**], H.4.3 [**INTERNET**].

General Terms
Algorithms, Performance, Design.

Keywords
Simulation tool, multi-hour network planning, WDM networks.

1. INTRODUCTION
The growth in the optical fiber capacity provided by the Wavelength Division Multiplexing (WDM) technology has created a gap between the amount of traffic that can be transmitted, and the amount of traffic that can be processed electronically in the switching nodes. This is called the "electronic switching bottleneck". It has the most evident impact on backbone networks, which carry the highest volume of traffic.

Several alternatives have been proposed to address this bottleneck. They intend to decrease the traffic that has to be switched electronically in the nodes, by allowing a more or less

sophisticated switching at the optical layer. Wavelength-Routing (WR) technology is an option commercially available that addresses the optical-electronic gap. In WR networks, traffic is carried onto transparent lightpaths. A lightpath occupies one transmission wavelength in each traversed link. The traffic carried in a lightpath is processed electronically at the ingress and egress nodes of the lightpath (where the lightpath is said to be dropped), but not at the intermediate transit nodes.

Figure 1 sketches a node of a WR network. The core of the optical part of the node is the Wavelength Switch Fabric (WSF), which allows the transparent switching of the WDM channels from its input to its output ports. The WSF can be constructed in a fixed or in a reconfigurable way. In the former, the connections between the input and output ports of the WSF are manually hard-wired and can not change on demand. In the latter, the WSF is implemented as a reconfigurable optical add/drop multiplexers (R-OADM) or reconfigurable wavelength crossconnects (R-WXC), so that the connections from input to output ports can be dynamically reconfigured in tens of milliseconds.
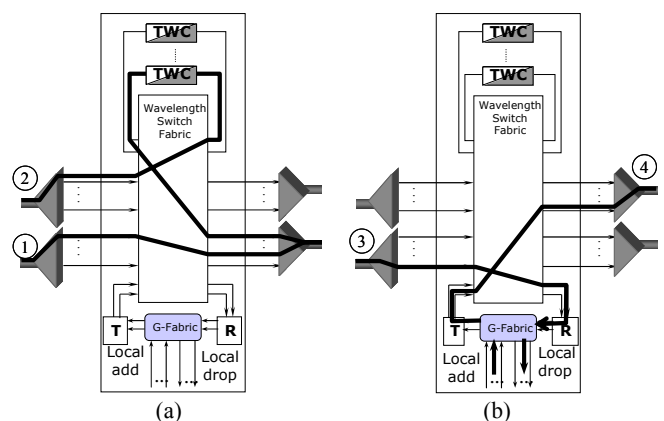

Figure 1. Functional blocks in the switching node.

Figure 1(a) identifies the two types of optically switched lightpaths without (1) or with (2) wavelength conversion. In the second case, the lightpath goes across a Tunable Wavelength Converter (TWC) device, which enables a wavelength conversion of a WDM channel in the optical domain. Lightpaths (3) and (4)

in Figure 1(b) illustrate the traffic grooming concept. Some portion of the traffic in lightpath (3) is dropped in the node. The rest of the traffic is groomed. That is, it is allocated in other lightpaths like (4) which are initiated in this node, sharing the lightpath with other grooming and/or *add* traffic.

Figure 1 helps us to identify the main components in the switching nodes which determine the overall cost of the network: a) the number of electro-optic (E/O) transmitters (T) and opto-electronic (O/E) receivers (R) in the node, b) the number of tunable wavelength converters (TWC) needed in the node, c) the size of the WSF component, and d) the electronic switching capacity required, given by the sum of the ingress, egress and grooming traffic.

The actual equipment required in a network is determined by the network planning decisions taken: (i) the *virtual Topology (VT) design*, which consists of the lightpaths to be configured, their traversing fibers, and their transmission wavelengths in each hop, and (ii) *the flow routing on top of the VT*, defining the way in which the traffic demand (electronic traffic flows offered to the network) is routed on top of the established lightpaths. The combined (i+ii) network planning problem to be solved takes the form of: "given a traffic demand and given a network topology (existing fiber links between nodes), determine the VT design and routing of traffic flows on top of it, which optimizes a given cost function". The VT design problem is also denoted as the RWA (Routing and Wavelength Assignment) problem. It is known to be a NP-hard problem ([1], [2], [3]). Obviously, the composed (i+ii) problem is also NP-hard.

Two types of optimization strategies exist when dealing with the network planning process. They are commonly called as static vs. dynamic planning (also off-line vs. on-line planning). In static planning, traffic demand is modeled as a fixed NxN traffic matrix, being N the number of nodes in the network. Each coordinate (i,j) means the total expected traffic from node i to node j (i.e. measured in Gbps). In the dynamic planning, the traffic demand may vary along the time, in different ways. If compared to static planning, dynamic planning allows a more realistic evaluation of the network performance. This paper focuses on multi-hour planning, as a type dynamic planning problem for WR networks. In multi-hour planning, the traffic demand is modeled as a traffic matrix which varies during the course of the day. The average traffic offered from node i to node j during an hour h is affected by the activity factor of node i and j during that time. The activity factor of each node is modeled to depend on the node local time, which itself depends on the node time zone. Thus, this model is suitable for capturing the traffic variation effect that appears in backbone networks that span large geographical areas, where nodes can be located in different time zones.

This paper presents the MatPlanWDM tool extension included in version 3 of the tool, designed to evaluate WR networks in a multi-hour traffic scenario. The first MatPlanWDM version was presented in [4]. MatPlanWDM is a MATLAB-based network planning application for WR networks, with or without the wavelength continuity constraint. It is developed as a set of MATLAB [5] functions, along with a graphical interface. The toolbox can be publicly downloaded at the MATLAB Central site [6]. Its goal is to allow the testing of heuristic optimization algorithms, providing an integrated framework to learn and research on WR networks planning. A MILP (Mixed Integer

Linear Programming) optimum search of the (i+ii) planning problem [7] is also integrated in the tool, so that their results can be compared to the ones achieved by the heuristic algorithms (except for large topologies). The tool is fully extensible in terms of network topologies, traffic demands and optimization algorithms. The multi-hour extension described in this paper is devoted for testing network planning algorithms in a multi-hour scenario. The tool automates the calculation of the performance metrics that allows to asses the merits of the planning algorithms under test, and to make planning decisions.

The authors feel that the enhancements made to MatPlanWDM empower its use as a teaching and as a research tool suitable for industry. To illustrate this, the tool is employed in an example analysis of a large geographical backbone network. The objective of the analysis is to estimate the benefits in network cost of having a WSF based on a reconfigurable wavelength crossconnects, instead of a hard-wired WSF.

The rest of the paper is organized as follows. Section 2 summarizes the related work. Section 3 presents the multi-hour extension in MatPlanWDM. A case study to exemplify the applicability of the tool is included in section 4. Finally, section 5 concludes.

2. RELATED WORK
2.1 Multi-hour planning
This section reviews some relevant contributions to multi-hour network planning. The time-varying traffic demand model used in this paper was first presented in [8]. This approach is suitable for generating traffic demands when the network spans over multiple time-zones which implies a non-coincidence of the busy hours. In [9] the authors use the traffic model in [8], and propose an online traffic engineering scheme for efficient routing of bandwidth guaranteed connections on a Multiprotocol Label Switching (MPLS) WDM network. First they consider the problem of designing a reconfigurable virtual topology that adapts to the traffic variation. Then, a proposed algorithm that takes into account possible rerouting of the label switched paths (LSPs) over the WDM virtual topology is applied. References [10] and [11] present Mixed Integer Linear Programming (MILP) formulations to solve the reconfiguration problem under multi-hour traffic. The formulation in [10] tries to minimize the number of changes in the virtual topology. By contrast in [11], the number of changes is not included in the objective function, but added to the formulation as a constraint.

An interesting work suitable for the multi-hour design problem is introduced in [12]. In this work a MILP is proposed to solve jointly the virtual topology design and the traffic routing problems, considering the traffic flows as LSPs with a given time-varying load. The method is called *Joint Configuration with Exact Traffic* (JCET) and it is compared with another two approaches: *Independent Configuration with Exact Traffic* (ICET) and *Unique Configuration with Maximal Traffic* (UCMT). The ICET approach optimizes each instant of time independently according to its instant expected traffic. The UCMT method optimizes the network using the maximal traffic matrix as input. The results from this work indicate that the UCMT is the least-efficient approach in terms of used resources due to the implicit over-dimensioning, while the ICET and the JCET yield to a similar

cost. ICET and UCMT strategies are used in the example in section 4 to model the costs of a network based on reconfigurable WSFs and a network based on non-reconfigurable WSFs respectively.

2.2 Optimization tools for WR networks

This section briefly overviews some relevant non-commercial planning tools, for WR networks. Naturally, a wide range of commercial applications also exists, for the dimensioning of WDM networks [13-15]. Nevertheless, these tools do not made public their underlying algorithmic details, and can not be extended by the researchers. Therefore, they are out of the scope of this survey.

The existing non-commercial planning tools for WR networks are mainly oriented to dynamic optimization. The GMPLS Lightwave Agile Switching Simulator (GLASS) [16] is a simulation platform built as an evolution of the MERLiN (Modeling Evaluation and Research of Lightwave Network) project, which was discontinued in 2001 [17]. The GLASS tool was developed at the National Institute of Standards and Technology (NIST). GLASS is of free use, and its last public version update occurred in March 2006. It is implemented in Java, and employs the SSF/SSFNet [16] discrete event simulation framework as its simulation kernel. The GLASS core is designed as a command-line simulator, where the simulation setup is defined by a script file. The GLASS core executes the simulation and writes binary dump files that can be post-processed by customized readers.

The *Optical WDM Network Simulator* (*OWns*) [18] tool, was developed at the Washington University, as a tool built on top of the well-known network simulator *ns* [19]. The *OWns* facilitates the study of RWA dynamic algorithms in WDM networks. Unfortunately, the tool upgrading stopped in 2001.

When compared to MatPlanWDM, the benefits of our proposal are based on the more powerful framework that MATLAB provides. Neither Java language (in GLASS platform) nor C++ language (in OWns platform) offer the mathematical functionality and flexibility that is available for MATLAB programmers. This permits the MatPlanWDM user a fast implementation and test of complex algorithms. In addition, the GLASS tool requires training in a complex class hierarchy of Java classes, before being able to implement new modules.

3. MATPLANWDM VERSION 3 EXTENSION FOR MULTI-HOUR ANALYSIS

The MatPlanWDM tool has been implemented as a MATLAB [5] toolbox, and can be publicly downloaded in [6]. All the functions in the toolbox are documented, and open for free usage. This section briefly overviews MatPlanWDM version 3 focusing on the functionalities employed to carry out the multi-hour analysis described in section 4. They are the following: (i) virtual topology design, (ii) multi-hour analysis, (iii) physical topologies generation, and (iv) generation and normalization of traffic matrixes. Other novel functionalities present in MatPlanWDM v3, but not directly related to the multi-hour analysis (i.e. the *what-if* analysis, or the physical topology generation GUIs), or a thorough description of the toolbox internal structure and MatPlanWDM architecture, are out of the scope of this paper.

3.1 Virtual topology design

Figure 2 shows the MatPlanWDM Graphical User Interface (GUI) implemented for the virtual topology design. The workspace of the GUI is divided into three areas: input data (left side area), plot area (middle), and results report area (right side area).

The user should define the input parameters for the simulation in the *input area*. They are specified according to three files: (1) a text file describing the physical topology (*.phys* file), (2) a text file describing the traffic matrix (*.traff* file), (3) a MATLAB code file (*.m* extension), implementing the planning algorithm to be applied. This latter module can receive a user defined input string for initialization.

The *.phys* files contain the list of nodes and fibre links in the network. Per node information is composed of the node *X* and *Y* coordinates measured in kilometres over a Euclidean plane, number of E/O transmitters, O/E receivers, number of TWCs, node population, and node type (or node level). Per link information is the maximum number of wavelengths per link. The capacity in Gbps of the lightpaths is also defined. The *.traff* files contain a matrix of offered traffic for each ingress-egress node pair, measured in Gbps. The planning algorithm module is an *.m* file. The user can choose a built-in heuristic algorithm, or implement its own one. Current planning algorithms for the virtual topology design included in MatPlanWDM v3 distribution are: HLDA, TILDA, RLDA and MLDA algorithms described in [21], and the heuristic algorithm presented in [22], which is employed in the multi-hour analysis in section 4. The implementation by the user of new algorithms has been facilitated in MatPlanWDMv3 (see section 3.3). The user can also select to use a built-in MILP search of the optimum solution instead of a heuristic planning algorithm. The MILP algorithm can be tuned in two ways: allowing or not wavelength conversion, and selecting among 5 different optimization objective functions. Optimum solutions have been obtained for topologies of up to 12 nodes, in an Intel© Pentium© M730 processor with 1.6 GHz and 512 MB of RAM.

The *Design* button triggers the algorithm execution. The results of the planning algorithm are the VT design and the routing of the flows on top of the VT. MatPlanWDM calculates some relevant indicators of the WR network cost and performance. This eases the evaluation and comparison among different solutions. The provided indicators belong to three categories: (i) cost indicators (i.e. number of used transmitters/receivers/converters per node), (ii) performance indicators (i.e. network congestion, which is the traffic carried by the highest loaded lightpath), and (iii) physical impairment indicators, which give an insight into the optical signal impairments suffered *in each lightpath* (i.e. the number of physical hops, the number of wavelength conversions, or the propagation distance in kilometers).

The planning solution found and its performance and cost merits are written into a report in the text field at the *results report area* (right side in Figure 2). The user can save the report in a *.results* text file for later use. In addition, the solution found can be graphically observed in two different manners. The *Physical Topology* panel plots the physical topology of the design. The user can select a particular lightpath, so that the traversing fiber links of the lightpath are highlighted in the physical topology, together with the wavelength in each hop. The *Virtual Topology*

panel draws the virtual topology graph. The user can select a particular high level traffic flow from the input parameters, so that the traversing lightpaths are highlighted in the virtual topology.
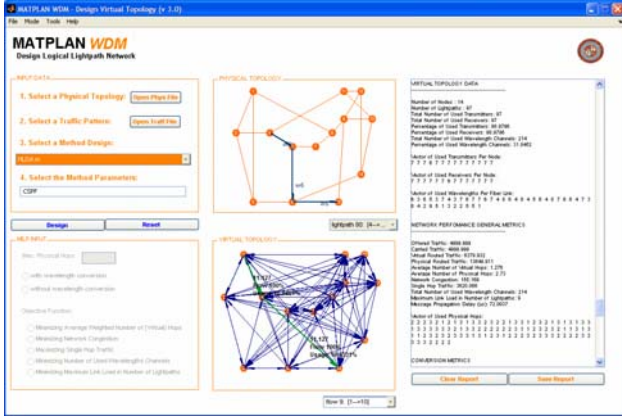

Figure 2. Virtual topology design window.

3.2 Multi-hour analysis

The multi-hour analysis GUI allows the user to carry out a full multi-hour test for a pre-built or user defined multi-hour planning algorithm. Figure 3 displays the interface window. In the input data panel (left-up side) the user selects (i) the physical topology file, (ii) the traffic matrix file, (iii) the per-node time-zone information, and (iv) the multi-hour planning algorithm.

The physical topology selected is plotted into the *Physical Topology* panel. The time zone of each node is introduced in a pop-up menu when the *Node Timezones* button is pressed. The time-zone of each node is represented as the time offset respecting to Universal Time Coordinated (UTC). The multi-hour planning algorithm is a *.m* file implementing a planning algorithm.

After pressing the *Start* button, the algorithm starts the simulation, executing the following iterations:

1. The UTC time which we denote as *t*, is set to *t*=0h. The variables storing the current network state (which we denote as *S*) are emptied: they are the current virtual topology and current routing of the carried flows on top of it.

2. The traffic matrix for the current UTC time (T_t) is computed, applying the Linearity to Provider and Consumer (LPCA) methodology in [8]. This means that:

$$T_t(i,j) = \begin{cases} T(i,j) \cdot activity(i,t) \cdot activity(j,t), if\ i \neq j \\ 0, if\ i = j \end{cases}$$

$$activity(i,t) = \begin{cases} 0.1\ if\ local\ time \in [0:00,06:00) \\ 1-0.9 \left(\cos \left(\frac{localtime-6h}{18h}\pi \right) \right)^{10}\ otherwise \end{cases}$$

(1)

3. The planning algorithm is executed by passing as input parameters the selected physical topology, the T_t traffic matrix, and the current network state *S*. The algorithm is responsible for calculating the new network state. Note that algorithms that react to changes in the traffic matrixes in any way can be implemented and tested under this scheme. For instance, algorithms can favor solutions that do not reroute lightpaths, or that do not reroute flows, or any other constraint.

4. Update the new network state *S*, increment the UTC time 1 hour and go to step 2. After 25 executions, the process stops. Note that this means that simulation at UTC time *t*=0:00h is executed twice: the first one is discarded as it assumed an empty network initial state.

After the simulation is completed, per-hour reports can be observed in the *Performance reports* panel by selecting the appropriate time at the *Hourly metrics* selector. Per node information reports can be generated that summarize the evolution of one selected metric across the nodes and along time. This provides fast access to relevant information like the time evolution in the number of used transmitters, receivers or converters.
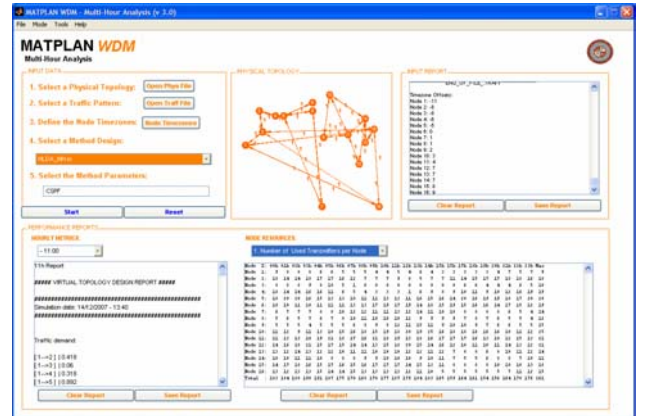

Figure 3. Multi-hour analysis design window.

3.3 Integration of user-defined planning algorithms

MatPlanWDM tool is distributed with a set of planning algorithms already built-in. Each planning algorithm is implemented as a MATLAB function with a fixed signature (input parameters and output results). MatPlanWDM can be easily extended by the user with new planning algorithms. To integrate a new algorithm, the algorithm code *.m* file has just to be stored in the designated directory. The process of implementing new planning algorithms is facilitated by a set of libraries available to the user in different directories of the MatPlanWDM toolbox:

- *library_Graph*: Includes general algorithms in graphs. Version 3 of the tool includes algorithms for solving the shortest path problem, the capacitated shortest path problem

and the *k*-shortest path problem following the path removal algorithm in [23].

- *library_WA*: Includes heuristics for the WA (Wavelength Assignment) subproblem: for a lightpath request between an ingress-egress node pair in a given physical topology, and given the route of the lightpath, the algorithm selects the wavelength assignment in each hop with or without the wavelength continuity constraint. Two algorithms are implemented nowadays. One of them is the first-fit [7] algorithm for non-wavelength convertible networks. The other one is a general graph conversion technique similar to the LEast Converter First (LEC) and Least Conversion Cost First (LCC), both used in [24], and the graph conversion technique used in [25].

- *library_RWA*: Includes heuristics for the RWA subproblem: for a lightpath request between an ingress-egress node pair, in a given physical topology, the algorithm calculates a route for the lightpath including the wavelength assignment in each hop, with or without the wavelength continuity constraint. The heuristics implemented at this moment are the Joint Wavelength-Route Selection (JWRS) [7] and the Wavelength- and Converter- Aware Algorithm (WCA) [24].

- *library_RRWA*: Includes heuristics for the RRWA (Rerouting and RWA) subproblem: this is similar to the RWA one. The only difference lays on the possibility to reroute existing lightpaths in the network, in order to accommodate the new lightpath request. The heuristics currently implemented are the Auxiliary Graph (AG) algorithm [7] and [26]. This type of algorithms is useful for the design of multi-hour algorithms, which adapt the planning decisions to the variations of the traffic matrix.

- *library_FR*: Includes heuristics for the routing of traffic flows on top of a given topology. Two algorithms are currently implemented: one for solving the minimum cost flow problem [27], and the other for an optimal multicommodity flow assignment problem [28]. The algorithms implemented for solving both problems are based on a Linear Programming (LP) formulation, solved optimally using the *linprog* LP solver included in MATLAB.

3.4 Traffic matrix generation interface

This interface allows the user to generate a *.traff* file representing a traffic matrix. Figure 4 displays the workspace window for this option. The user initiates the process by selecting the number of nodes *N* in the network. After this, the user can select in the *Pattern generation* selector, among different random ways of generating a matrix. Five modes are available: four of them are simpler, and based on the uniform distribution. The fifth mode allows creating a traffic matrix according to the model described in [29]. This latter model applies the information of node population and node position present in a selected *.phys* file. The user should define a set of factors that design a traffic matrix where the traffic between two nodes depends of a random factor, the population of the two nodes, and the distance between them, in different manners (see [29] for details).
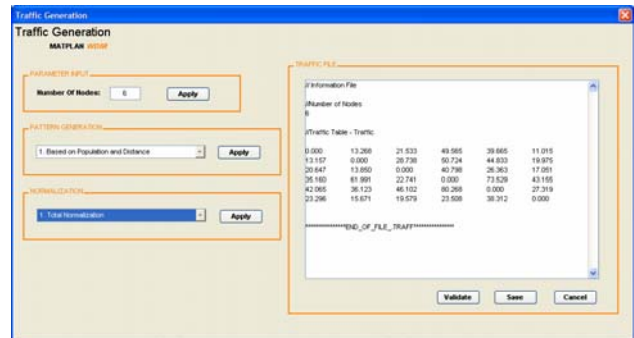

Figure 4. Traffic matrix generation window.

After completing this stage, the matrix generated is reported in the *Traffic file* field in the right side of the window. The user can modify it manually, or apply an automatic normalization of the matrix. Three types of normalization are implemented at the moment: total, row and column normalization [29]. The first adjusts the traffic matrix so that the total traffic offered to the network matches a user defined value (in Gbps). The second (third) modifies the matrix so that the *i*-th row (column) of the matrix sums x_i, being x_i, $i=1,...,N$ a vector defined by the user. Note that this means that the traffic transmitted (received) by node *i* is fixed to exactly x_i Gbps. Finally, the user can validate the format of the *.traff* file and save it into the file system with the *Validate* and *Save* buttons.

4. MULTI-HOUR EXAMPLE ANALYSIS

This section describes the operation of the MatPlanWDM tool in the analysis of a realistic WR network in the multi-hour scenario. The network under study is composed of 15 nodes covering the five continents. Table 1 enumerates the nodes and Figure 5 illustrates the connections among them. The objective of our analysis is to compare the cost of the network in two different situations: (1) network nodes are based on non-reconfigurable WSFs, (2) network nodes are based on reconfigurable WSFs. We assume that both alternatives are free to adapt to traffic variations by rerouting the traffic flows on top of the virtual topology. The difference between them stands on that in the first case, the virtual topology in the network can not change along the day to contribute to the adaptation to traffic changes, while in the second case, the reconfigurable WSFs can reroute, setup or tear lightpaths dynamically. In theory, lower resources would be needed in reconfigurable networks because of the higher degree of flexibility available, at a cost of an increase in the WSF expenses. This is an actual hot-topic in current WR network design. Let us show how the MatPlanWDM tool can help us to estimate the merits of each alternative.

We measure the cost of each option as the number of E/O transmitters used in the network. Note that this number is equal to the number of O/E receivers and number of existing lightpaths. We assume no-wavelength conversion, by forcing zero wavelength converters (TWCs) available in each node. We employ the ICET and UCMT strategies to model the costs of a network based on reconfigurable WSFs and a network based on non-reconfigurable WSFs respectively:

- *Reconfigurable case*: In the reconfigurable case, we let the multi-hour planning algorithm to decide the VT and flow routing solution independently in each hour of the day. After the simulation is completed, we will observe for each node i, the number of transmitters used at the hour t, n_{it}, $i=1,...,15$, $t=1,...,24$. The number of transmitters needed in each node i, N_i, is the maximum number used along the day. Therefore, the number of transmitters needed in the whole network is given by (2):

$$n = \sum_{i=1}^{15}\left\{ \max_{t=1,...,24} \{n_{it}\} \right\} \qquad (2)$$

- *Non-reconfigurable case*: In the non-reconfigurable case, the virtual topology has to be dimensioned for the worst case traffic matrix following the UCMT strategy [12]. Attending to this, the worst case traffic matrix to be employed is just the matrix T that the MatPlanWDM multi-hour analysis interface used as a source to calculate the T_t, $t=1,..,24$ matrixes. In summary, the number of transmitters used in the non-reconfigurable case, is the one planned by a conventional (non multi-hour) algorithm in a normal *Virtual topology design* analysis, for the maximal traffic matrix T. Note that this way of proceed does not favor the non-reconfigurable case as the maximum traffic between a node pair is in general not simultaneous to the maximum traffic between other node pair. Furthermore, this strategy does not exploit the possibility of traffic flows rerouting along time. Thus, it can be seen as a worst-case model for the non-reconfigurable alternative.
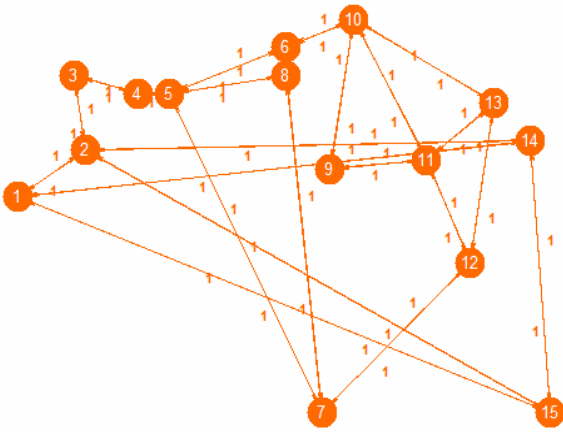

Figure 5. Test topology.

Node	Name	Population	Timezone
1	Honolulu	378155	-11
2	Los Angeles	3789981	-8
3	Vancouver	545671	-8
4	Chicago	2886251	-6
5	New York	8084316	-5
6	London	6638109	0
7	Cape Town	2415408	1
8	Paris	2125246	1
9	Athens	745514	2
10	Moscow	10101500	3
11	New Delhi	12791458	4
12	Beijing	13820000	7
13	Singapore	4017733	7
14	Tokyo	8134688	8
15	Sydney	3997321	9

Table 1. Node information of the network under test.

Let us show how this comparative analysis can be conducted using the MatPlanWDM tool. First, we use the physical topology generation tool to create the *.phys* file with the network under study. The maximum number of wavelengths per fiber, and the number of available transmitters and receivers per node are set to infinite. The number of TWCs is set to zero. Second, we should create the traffic matrix T, which will be used by the *Multi-hour analysis* functionality as a source to create the T_t, $t=1,...,24$ traffic matrixes, one for each hour in a day. To do it, we can use the *Traffic generation interface*. The traffic model we choose is the one described in [8], for which the traffic between two nodes is proportional to the product of the two node populations, independently of node distance. We use the *Total normalization* function to fix the total traffic offered by this matrix (sum of all the coordinates of the matrix) to 2 Tbps.

After this, we feed the *Multi-hour analysis* interface to evaluate the merits of the WR network with reconfigurable WSFs. We introduce the *.phys* and *.traff* files previously generated, and the time zone information for each node. The planning heuristic algorithm employed in our analysis is the one described in [22]. This planning algorithm has not been designed specifically for multi-hour planning, and does not use the information about how the network state is at a given time. This situation is coherent to the ICET strategy we follow (note that [12] presents a case study where an ICET strategy yields to results close to the optimum JCET MILP solution). The planning algorithm has been carefully chosen, as it is designed to create the virtual topology which minimizes the number of transmitters employed in the network. Therefore, it is well suited to approximate a best-case situation, favorable to the reconfigurable network. The results calculated by the tool are shown in Table 2(a): one row per node (1...15) and one column per hour (1...24).

To complete the comparison, the *Virtual topology design* interface is used to make the non-reconfigurable WSF part of the evaluation. The maximal T matrix (used as a source of the T_t, $t=1,...,24$ matrixes in the multi-hour analysis) is employed here, together with the same planning algorithm applied previously. Results obtained are collected in Table 2(b), where the values per node are compared for the reconfigurable (R) and non-reconfigurable (NR) case.

The results obtained show that carrying the traffic demand requires 204 transmitters (lightpaths) in the reconfigurable network, and 230 transmitters (a 12.75% more) in the non—reconfigurable case. In the reconfigurable case, the results per-hour reveal large variations in the number used transmitters. Unfortunately, as the nodes have to be dimensioned to the maximum number of transmitters used along the day, the benefits of the reconfigurable network shrink. The R/NR comparison values even show nodes where the number of transmitters needed is lower in the NR case. The reader should note that the ICET/UCMT comparison implies that the *sum* of transmitters (204 vs 230) must be better for the reconfigurable case, as it is. However it does not imply a lower number of transmitters in each node.

The implementation of the algorithm is included in the current version of MatPlanWDM, so that the readers can check the values obtained. Of course, a much larger set of tests should be conducted in order to extract valuable comparisons among the two alternatives: more specific algorithms could be designed; a multiplicity of traffic matrixes randomly generated and normalized in different ways (i.e. using the traffic generator tool) could be used, etc. The reader should consider that this section is not intended to provide a thorough analysis to the reconfigurable-WSF question at all. Our aim is to illustrate how the new version of MatPlanWDM tool can support the dimension planning in WR networks, and how it can serve to address some of the relevant questions a network operator must face.

5. CONCLUSIONS AND FURTHER WORK

This paper describes the MatPlanWDM version 3 extension for multi-hour analysis, along with an application example to illustrate its merits. MatPlanWDM software can be publicly downloaded in [6]. Feedback is welcome from the users. The fourth version of the tool is under preparation. Its main upgrade is the addition of an event-driven core to provide a more specific analysis mode to test dynamic planning algorithms.

6. ACKNOWLEDGMENTS

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	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Max		R	NR
1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2		2	2
2	8	7	7	7	9	7	5	3	1	2	3	2	2	1	1	3	5	7	7	7	8	8	11	8	11		11	12
3	1	1	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	3		3	2
4	4	5	5	5	6	3	1	1	1	1	2	1	1	2	4	6	6	6	5	5	5	4	3	5	6		6	10
5	15	11	11	9	7	3	3	2	4	3	5	3	5	12	15	17	15	16	16	11	11	12	9	14	17		17	22
6	2	2	1	2	4	2	3	4	8	13	15	15	15	15	15	13	16	15	13	11	8	5	2	2	16		16	19
7	1	1	1	1	2	1	3	4	5	6	8	6	6	6	6	7	5	6	5	4	4	3	1	1	8		8	8
8	1	1	1	1	1	1	2	3	4	5	7	6	5	6	6	5	5	5	5	4	3	2	1	1	7		7	7
9	1	1	1	1	1	1	1	2	3	3	5	3	3	3	2	4	2	2	2	1	1	1	1	1	5		5	3
10	2	3	3	3	5	10	15	21	21	22	24	24	23	25	22	21	19	17	12	13	4	2	2	1	25		25	28
11	2	4	4	6	13	18	27	26	28	29	30	28	28	26	26	23	22	18	11	5	3	3	3	2	30		30	34
12	4	13	20	22	23	25	24	27	26	28	29	29	29	25	23	15	8	4	4	3	3	4	3	2	29		29	35
13	2	4	6	8	9	9	9	9	10	11	11	10	11	9	8	5	2	1	1	1	1	1	1	1	11		11	13
14	7	12	11	13	18	16	18	18	18	18	22	17	18	16	10	5	2	4	2	2	2	1	2	3	22		22	22
15	4	6	8	8	10	7	8	9	10	9	12	10	8	5	3	1	1	2	1	1	1	1	2	3	12		12	13
Sum	55	72	82	88	111	106	121	131	141	151	175	156	156	153	143	129	107	108	88	72	59	52	46	46	204		204	230

(a)   (b)

Table 2. Multi-hour analysis results.