Virtual Topology Design and Reconfiguration using Cognition: Performance Evaluation in Case of Failure

N. Fernández, R. J. Durán, I. de Miguel,
N. Merayo, P. Fernández, J. C. Aguado,
R. M. Lorenzo, E. J. Abril
Universidad de Valladolid,
ETSI de Telecomunicación
Paseo de Belén 15
47011 Valladolid, Spain
natalia.fernandez@tel.uva.es, rduran@tel.uva.es

E. Palkopoulou, I. Tomkos
Athens Information Technology Center
19. 5 km Markopoulou Ave.
19002 Peania, Athens, Greece

Abstract—**In this paper, a new reconfiguration policy and a new algorithm for the virtual topology design, named CONGA-VTD (Cost-OptimizatioN Genetic Algorithm for Virtual Topology Design) for Wavelength-Routed Optical Networks are proposed. The objectives of both proposals are to minimize the Packet Loss Ratio (PLR) and the OPerational EXpenditures (OPEX). A simulation study is presented to demonstrate the advantages of the new techniques in both normal operation and in presence of failures. The reconfiguration policy is compared to two static ones to determine the benefits of the reconfiguration process in terms of PLR, OPEX and resources in operation.**

Keywords—Cable Failure, Traffic Forecasting, Genetic Algorithm, Operational Expenditures, Packet Loss Ratio (PLR), Reconfiguration, Virtual Topology Design.

I. INTRODUCTION

While most of current networks cannot vary their topologies easily, Wavelength-Routed Optical Networks (WRONs) offer this possibility by the reconfiguration of their virtual topologies, that is, the set of optical connections (or lightpaths) established in the network [1].

The design of the virtual (or logical) topology is an NP-complete problem that consists of three subproblems [2, 3]: (1) determining the set of lightpaths to be established in the network, (2) assigning network resources for each lightpath, i.e., solving the Routing and Wavelength Assignment (RWA) problem, and (3) routing the traffic through the designed virtual topology. In the design of these virtual topologies, different parameters can be used as the optimization objective or even using several of them in a multiobjective optimization. The most interesting approaches to solve multiobjective optimization problems are targeted to obtain the Pareto Optimal Set (POS), i.e., a set of solutions where each solution (virtual topology) is characterized because it cannot be simultaneously improved in terms of all optimization objectives. Some criteria that can be considered as optimization objectives are the congestion (the traffic carried by the most loaded lightpath), the end-to-end delay, the energy consumption or the cost.

Network costs are usually divided into CAPital EXpenditures (CAPEX) and OPerational EXpenditures (OPEX). CAPEX are related with the cost of the initial infrastructure, while OPEX are the costs related to the network usage, and thus include space rentals, energy consumption, network maintenance, and fault reparation costs (note that the less usage that a device has, the longer its effective life is). While CAPEX should be taken into account in the provisioning stage of the network, OPEX can be minimized by the optimization of the network operation. Since communication networks handle continuous variations of traffic demands, some network elements can be temporarily powered-off, thereby reducing OPEX due to reduced energy consumption.

When a virtual topology is established, one possible WRON configuration is that lightpaths remain permanently established and, only in exceptional circumstances (e.g., a fiber failure), these optical connections are modified. This is called static WRON and they are the most widespread option nowadays. The virtual topologies of these networks should be designed overdimensioning the resources in operation, i.e., establishing more lightpaths than necessary in order to avoid losses in case of a high level of traffic or equipment failures. Obviously, such overdimensioning leads to an increment in the network costs.

An alternative solution to static WRONs consists in optimizing resource usage and energy consumption by means of virtual topology reconfiguration, i.e., adapting the virtual topology depending on both the network state (i.e., available and operative devices in the network) and the current traffic demand. This technique offers many benefits [4] in terms of cost and energy saving, as well as on a reducing the set of resources used, depending on the traffic demands. However, when facing a reconfiguration event in IP over WRON networks, the modification of the optical connectivity of the nodes leads to temporal instability of the IP routing tables, and this issue may translate in packet losses. Hence, not only is the design of the most efficient logical topology for the current conditions an aspect that should be taken into account, but also the analysis of the traffic disruption that can appear during the reconfiguration process.

In this reconfiguration process [4, 5], so as to decide when to trigger a reconfiguration, the literature proposes several approaches that can be classified into off-line [5, 6] and online policies [7]. The off-line reconfiguration is based on predesigned virtual topologies according to an estimation of traffic evolution and it provides the sequence of virtual topologies to establish in each moment. On the contrary, on-line policies analyze the network traffic on real time to decide when to trigger the reconfiguration and to design logical topologies adapted to that traffic.

A Cognitive Heterogeneous Reconfigurable Optical Network (CHRON) [8] is an optical network based on lightpath establishment, which relies on cognitive techniques to offer higher capability and flexibility in a transport network, for instance by efficiently using resources in order to minimize the network cost while ensuring the demanded bandwidth. In order to fulfill this objective, this architecture is continuously monitoring the network status (including traffic, quality of transmission and devices status) and it is able to change its configuration to improve the overall performance of the network.

In previous studies [9, 10] we have proposed a set of algorithms for virtual topology design but they do not take into account the impact of reconfiguration and do not implement any reconfiguration policy. In this work, we propose two new elements: a novel on-line reconfiguration policy and a new method to design the virtual topology adapted to that reconfiguration policy. This work focuses on a centralized control scenario for a CHRON where a single virtual topology is embedded to optimize the transport of the IP traffic carried by the network operator. The reconfiguration policy has as objectives the reduction of both the Packet Loss Ratio (PLR) and the network operational costs (OPEX). The new virtual topology design method, CONGA-VTD (Cost-OptimizatioN Genetic Algorithm for Virtual Topology Design) is a three-objective genetic algorithm to design the most efficient virtual topologies according to the traffic conditions by (1) minimizing the number of lightpaths that need to be changed from the current virtual topology to the new one, (2) minimizing the OPEX and (3) minimizing the congestion. Instead of combining these three objectives in only one by using weights, CONGA-VTD provides, in a single execution, the set of solutions that belong to the Pareto Optimal Set (POS) in terms of those three objectives (i.e., each solution provides a different trade-off of the optimization parameters). Therefore, the virtual topology that is finally implemented in the network is selected *a posteriori* from those candidate solutions following a procedure that will be later explained.

Moreover, two cognitive techniques have been included in the reconfiguration process to enhance its performance. First of all, by forecasting the future traffic demands, and secondly, by complementing the virtual topology design algorithm with a Knowledge Base (KB) where solutions successfully used in the past are stored for potential reuse in the future. Then, CONGA-VTD is able to use this information by employing a cognitive technique to select the most useful information in the KB for the current and future traffic conditions.

In order to show the advantages of the new proposals, we have compared the performance of static and reconfigurable networks using the proposed methods, when facing different traffic demands, and we show the benefits of employing the reconfiguration mechanism. In particular, we analyze the event of a cable failure. In a static network, the adaptation to that event is carried out by rerouting traffic by other non-affected lightpaths established in the network (i.e., we assume restoration at the IP layer), while in the reconfigurable network (like CHRON), the virtual topology reconfiguration procedure takes place.

The remainder of this paper is organized as follows. Section 2 introduces the virtual topology design and reconfiguration system that has been implemented and the explanation of each module. Section 3 describes the simulation results in order to show the benefits of the methods, and finally, section 4, summarizes the main conclusions of this work.

II. Cognitive Virtual Topology Design and Reconfiguration

The main element of a CHRON network is the Cognitive Decision System (CDS), as it is the component in charge of making decisions for a correct operation of the network. The CDS architecture is defined in [8] and consists of different interconnected modules, each one in charge of performing different tasks. As explained before, CHRON supports the establishment of a virtual topology. For this purpose, the CDS uses two of its submodules [8]: the Network Planner and Decision Maker (NPDM) module, and the Virtual Topology Design (VTD) module. The virtual topology reconfiguration process takes place due to a change in the traffic pattern, a modification of the physical network or to react when facing a failure in network equipment or infrastructure, but also to increase the performance of the overall network. Therefore, the NPDM triggers the virtual topology reconfiguration periodically and consists of three subtasks:

- *Forecasting the traffic in the near future*: This information is used for both the design of the virtual topology and to make the decision about performing a virtual topology reconfiguration or not. This task is performed by the NPDM.
- *Virtual topology design*: The VTD module performs this task. Although any method capable of solving the three subproblems involved in the design of the virtual topology can be employed, in this paper, we propose a new algorithm for this aim, CONGA-VTD.
- *Decide whether the current virtual topology should be reconfigured or not*. Moreover, in the case of a reconfiguration, it selects the best virtual topology among those provided by the VTD module.

In the operation of the CHRON network, the beginning of the virtual topology reconfiguration process (which can lead to a reconfiguration or not) is periodically triggered by the NPDM. The time between two consecutive reconfiguration process events is called time-slot. The description of this process is shown in Fig. 1. Let us suppose that the current time-slot is *h*. Then, this process should decide how to act in the next time-slot, *h+1*.

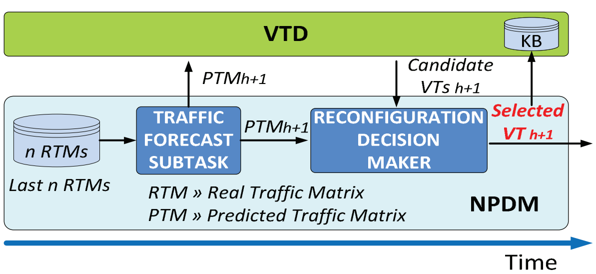

Fig. 1. Description of the virtual topology reconfiguration policy. Interaction between NPDM and VTD of CHRON [8].

The NPDM relies on the Real Traffic Matrixes (*RTM*) database. Such database contains the set of *n* *RTMs* measured in the last *n* time-slots, i.e., from time-slot *h* to slot *h-(n-1)*. These RTMs are the inputs of the Traffic Forecast Subtask. With that information, this subtask estimates the traffic matrix for the next time-slot, i.e., the Predicted Traffic Matrix (PTM_{h+1}). Then, the VTD module designs a set of virtual topologies adapted to that predicted traffic, PTM_{h+1}. The virtual topologies proposed are then evaluated by the Reconfiguration Decision Maker which makes the decision about keeping the same virtual topology or reconfiguring it considering the expected traffic, PTM_{h+1}. Moreover, this process is in charge of selecting the virtual topology that will be established (in case of reconfiguration) among those ones proposed by the VTD module.

When the virtual topology is selected (*Selected* VT_{h+1} in Fig. 1), it is established in the physical network in the time *h+1*. When, the system has information about the real traffic (*RTM*) in slot *h+1*, the real traffic losses and the real OPEX are evaluated. Moreover, when CONGA-VTD is used to design the virtual topology, the selected virtual topology is introduced in a Knowledge Base (KB), and the VTD module (equipped with CONGA-VTD) can use this information to design new solutions in the future as it will be explained later.

The model of Fig. 1 contains two cognitive parts. First of all, the Traffic Forecast Subtask module is able to determine the traffic in the next hours. Secondly, when CONGA-VTD is used, it learns from previous configurations by means of the KB.

A. *Traffic Forecast Subtask*

The Traffic Forecast Subtask is performed by the NPDM. It receives as input the *RTM* database (i.e., the set of the last *n* RTMs), and it returns a forecast of the traffic matrixes for the next time-slots. Fig. 2 describes this process considering that the current time-slot is *h*. *RTM* is referred to Real Traffic Matrix and *PTMs* are the Predicted Traffic Matrixes. Even when the traffic forecast module provides estimates for the traffic in the next *m* time-slots, only the PTM_{h+1} has been used in this work.

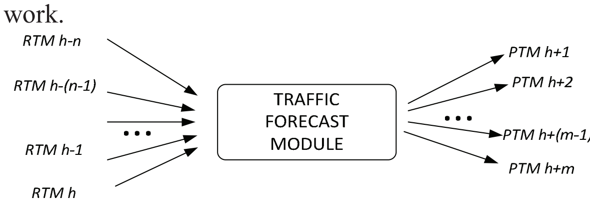

Fig. 2. Behaviour of the traffic forecast subtask.

ARIMA (AutoRegressive Integrated Moving Averages) was selected as the method implemented in the NPDM to estimate the next traffic matrixes. ARIMA is a statistical model which uses variations and data regressions in order to find patterns to model data or to forecast future data [11].

By means of this technique, the module is able to forecast the traffic in the near future, and thus is able to make the best decision about the reconfiguration of the virtual topology.

B. *Virtual Topology Design Process*

As previously explained, the VTD module will perform this process, and it can use any of the previously proposed methods to design the virtual topology (e.g. [9, 10, 12]). In this paper, we propose a new technique for the virtual topology design based on a genetic algorithm, called CONGA-VTD (Cost

OptimizatioN Genetic Algorithm for the Virtual Topology Design).

CONGA-VTD is a multiobjective (three-objectives) genetic algorithm to design virtual topologies with the aim of optimizing the network capacity (by minimizing the congestion), reducing the number of different lightpaths between the current and the proposed virtual topology for the next slot (in order to minimize the reconfiguration disruption), and minimizing the OPEX, which composed of the power consumption, space rental and maintenance and repair costs. However, the space rental cannot be optimized during the operation, as it depends on all the equipment installed in the network (idle and in operation).

CONGA-VTD is able to solve jointly the three subproblems of the virtual topology design. As other multiobjective algorithms, it is targeted to obtain the Pareto Optimal Set (POS). In the set of solutions that CONGA-VTD returns, it is also included the currently established virtual topology (as it is the one with zero number of changes between the current and the new virtual topology). Hence, keeping that topology (i.e., not reconfiguring) is also a candidate solution for the next time slot.

The new method is based on GAPDELT [10] (Genetic Algorithm to Provision the network and to Design the Logical Topology). GAPDELT is a multiobjective genetic algorithm to design a set of virtual topologies that constitute a good estimate of the POS with two design objectives: minimizing the congestion and the number of lightpaths composing the virtual topology. That algorithm was enhanced with additional capabilities, and in [9] we presented P-SC^{T}-IA-GAPDELT (Power-optimized, and enhanced with Simple Cognition and Tabu list, Impairment Aware GAPDELT), an algorithm to minimize the congestion and the power consumption, which includes a simple cognitive technique to enhance the genetic algorithm allowing the achievement of better virtual topologies in less time. However, none of these methods considers the virtual topology currently established when designing the new one in order to minimize network disruption, and thus they increase traffic losses in reconfiguration scenarios.

In contrast, CONGA-VTD designs virtual topologies taking into account the current network configuration and assessing the estimated traffic losses (if any), thus reducing its number while also minimizing OPEX costs and optimizing resource utilization. In order to estimate OPEX, the techno-economic model presented in [13] is used, which takes into account the costs of equipment such as transponders, EDFAs, optical cross-connects (OXCs) and IP/MPLS nodes, in terms of power consumption costs, rental costs, and maintenance and repair costs. This is a more realistic model than that implemented in P-SC^{T}-IA-GAPDELT [9], where we only considered the impact of energy consumption.

In reconfigurable environments, CONGA-VTD implements a simple cognitive technique which saves virtual topologies used in the past in a Knowledge Base (KB), so that they can be reused in the design of virtual topologies for future traffic demands. In this way, when a virtual topology proposed by CONGA-VTD is established (i.e., the network is reconfigured with that solution), it is stored in the Knowledge Base (KB). Then, when the method is launched again to find new virtual topologies for a future time-slot, it uses those solutions from the KB that better fit to the current traffic and network state, as starting points of the genetic algorithm. The method to select those best virtual topologies consists in evaluating the virtual topologies in the KB according to the current network state and estimated traffic matrix, and selecting those solutions composing the POS according to the three objectives of CONGA-VTD previously mentioned. Those selected solutions are included in the initial population of the genetic algorithm together with a set of randomly generated virtual topologies and other special ones, calculated *ad-hoc*, as described in [9]. Thanks to the use of the KB, CONGA-VTD finds better solutions in less time.

C. *Reconfiguration Decision Maker*

The Reconfiguration Decision Maker is the "leader" of this system. It determines when the reconfiguration is applied or not, and, in case of reconfiguration, it determines which virtual topology of those provided by the VTD module should be implemented. As previously explained, CONGA-VTD designs a set of topologies using the PTM_{h+1} provided by the Traffic Forecast Subtask. Then, the Reconfiguration Decision Maker makes a decision also based in the PTM_{h+1}. In particular, when assessing a virtual topology for potential reconfiguration, it takes into account the traffic that is temporally disrupted due to the instability of the routing tables due to the reconfiguration. When a reconfiguration event takes place, we have assumed that all the modifications to the virtual topology (tear down lightpaths and the establishing of the new ones) are done at the same time.

In order to estimate the PLR, we have assumed that all the traffic is lost until the routing tables become stable (except the traffic traversing the non-disrupted lightpaths). Moreover, we have made the assumption that when two or more lightpaths are established from node s to node *d* and any of these lightpaths are removed, all the traffic that previously used the affected lightpath will be sent through the rest of the lightpaths between nodes *s* to node *d* if there is enough capacity. Moreover, when a lightpath should transport more traffic than its capacity, the exceeding traffic is considered as lost traffic. As it can be seen, the method to estimate the PLR is complex and it cannot be applied in the genetic evolution as an objective if we want to perform a "long" evolution of the genetic algorithm.

Therefore, the PLR is only estimated and used when making the decision about the reconfiguration with the virtual topologies provided by CONGA-VTD.

In this way, the Reconfiguration Decision Maker evaluates all the virtual topologies proposed by the VTD module and the current established one in terms of traffic losses and the OPEX for the forecasted future traffic demand during the next time-slot. Then, this module chooses a virtual topology among all the candidate possibilities. The selected virtual topology will be that which generates the least losses (PLR), and if they generate the same amount of losses, that which generates the lowest OPEX will be selected. The PLR is evaluated calculating the traffic that cannot be routed of the total generated traffic. The selected solution can be the same virtual topology that it is currently established (so there would be no reconfiguration) or a different one (and thus reconfiguration would take place).

III. Simulation Results

The performance of the new reconfiguration policy and the virtual topology design have been analyzed by means of simulation. In these simulations, the 14-node Deutsche Telecom network has been used as the physical network assuming that each cable consists of two fibers, one per direction. A 64 fixed-grid channel configuration in each fiber has been used and no physical impairments have been considered. Each node is equipped with one hundred 10 Gbps transponders (each one composed of a transmitter and a receiver).

The OPEX are evaluated using the techno-economic model presented in [13] (which includes a model for fixed-grid networks as it is the one used in this study). The reference unit for the cost is the cost of one 10G transponder.

To generate traffic, we have used the model proposed by Gençata and Mukherjee [7] as this model has been used in other studies about reconfiguration of the network. It considers that the traffic between each pair of nodes (from node s to node d) at time t (in seconds) is given by eq. 1:

$$\lambda^{s,d}(t) = \Lambda^{s,d}\beta(t)\left[1+\frac{1}{2}\sin\left(\frac{2\pi 3600\,t}{86400}\right)\right] \qquad (1)$$

where $\Lambda^{s,d}$ is the average traffic from s to d in one day, i.e., 86400 seconds. $\beta(t)$ adds the bursty character to the traffic demand and it is randomly generated each time that this function is invoked using a uniform random variable between [1-ε, 1+ε], where ε is a user-defined parameter which controls the amount of burstiness. In this paper, $\Lambda^{s,d}$ has been generated randomly using an uniform distribution with mean between 3.5 and 6 Gbps for all source-destination pairs, and the degree of burstiness β has been set to 5%. The traffic demands are generated each hour. The results shown in the paper for different parameters are the average of those obtained in ten simulations with different values of $\Lambda^{s,d}$. Then, results are shown with 95% confidence intervals.

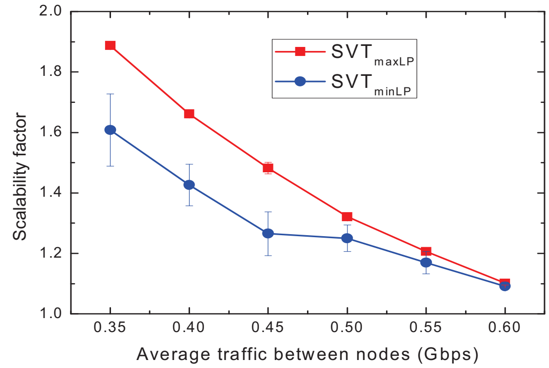

Fig. 3. Scalability factor of the static virtual topologies SVT_{maxLP} and SVT_{minLP}

The results of the proposed reconfiguration policy have been compared with those provided by two static WRONs. In these last networks, the virtual topologies are also designed by CONGA-VTD at the beginning of the simulation and for provisioning purposes we have assumed that the traffic between each pair of nodes is $\Lambda^{s,d}\cdot(1+0.05)\cdot(1+0.5)$, i.e., the maximum value it can take according to the model. As CONGA-VTD obtains a set of virtual topologies, two of them were selected as virtual topologies: the one that establishes the highest number of lightpaths (SVT_{maxLP}) and the one with the lowest number of lightpaths (SVT_{minLP}). It is important to remark that both virtual topologies can carry the maximum amount of traffic (according to the model) without exceeding the capacity of a lightpath. In Fig. 3, the scalability factor of both static virtual topologies has been shown. The scalability factor is the factor for which it is possible to multiply each value of $\Lambda^{s,d}$ without exceeding the lightpath capacity, and thus is related with the overprovisioning of that configuration.

In order to estimate the future or predicted traffic matrix (PTM_{h+1}), the traffic forecast process has been configured to use the real traffic matrixes from the last 48 time-slots, i.e., n was set to 48.

The time-slot duration (h) has been set to one hour. Then, each time that the virtual topology is reconfigured, it is considered that the routing tables are updated in one minute [14]. In order evaluate the performance of the method in the presence of a failure; a cable has been broken after four simulated days (hour 96). In the static WRONs, a cable break implies a modification of the routing tables in order to accommodate the traffic demand for restoration purposes.

A. Performance evolution with time

Initially, the evolution of the performance (in terms of PLR, OPEX and number of lightpaths composing the virtual topology) with time is shown. For these figures, the average traffic load between each pair of nodes has been set to 4 Gbps.

Fig. 4 shows (by means of a green line) the evolution of the average traffic load between all nodes as a function of time, which follows the model previously mentioned [7]. As discussed above, a cable fails in hour 96, which involves traffic losses, which are also shown in Fig. 4. The amount of lost traffic in the static networks is represented by means of red and blue lines, and the amount of lost traffic in the reconfigurable scenario is represented in black.

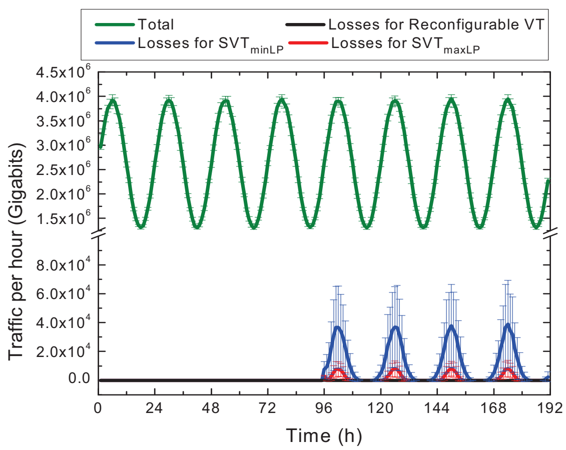

Fig. 4. Representation of total traffic and total losses for static virtual topologies and the reconfigurable one in 8 days for a average traffic between any two nodes of 4 Gbps. A cable failure appears at 96 hour.

Fig. 4 shows that the static virtual topologies have zero PLR in normal operation as they are slightly overprovisioned. However, when a cable fails, the reconfiguration of the routing tables (i.e., applying restoration in the electronic layer) cannot lead to a situation without traffic losses. In contrast, the reconfigurable network does not have traffic losses during the normal operation and it is able to adapt to the new situation after a network failure causing very low PLR.

Once that it is shown that the reconfigurable network (using CONGA-VTD) does not produce losses in network operation and that it can react against a network failure, the main advantages of reconfiguring the virtual topology are shown in Fig. 5 and 6. Fig. 5 shows the OPEX per hour of the three alternatives, while the number of lightpaths composing the established virtual topology is shown in Fig. 6.

As shown in Fig. 5, OPEX are not constant during the simulation. In fact, when the traffic decreases, the OPEX are also reduced as the power consumption of the IP layer is cut down. Moreover, the reconfigurable network decreases the OPEX of the network more than the static WRONs as it adapts the virtual topology to current traffic and network conditions. It is also worthy to note that it can reduce the OPEX without causing any PLR as it takes these parameters into account when making the decision about reconfiguring or not. On the other hand, the static network with lowest number of lightpaths established (SVT_{minLP}) has less OPEX than the other static network (SVT_{maxLP}), but it suffers more PLR (shown in Fig. 4) as its scalability factor is smaller than that of the SVT_{maxLP}.

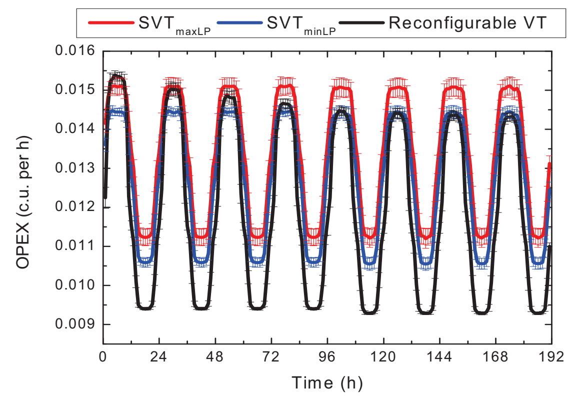

Fig. 5. OPEX per hour along 8 simulated days. The average traffic between nodes of 4 Gbps.

In Fig 6, we have represented the number of lightpaths in the virtual topology SVT_{maxLP} (in red), and in SVT_{minLP} (in blue). On the other hand, the number of lightpaths of the sequence of virtual topologies that the reconfiguration system selects is shown in black. Two different conclusions can be obtained from this figure: (1) the system learns when more information is saved in the KB because the number of lightpaths (for a similar network load) decreases with time when the reconfigurable scenario is considered, and (2) less lightpaths and resources are used and they can be dedicated to other services provided in the network (e.g., to the establishment of lightpaths on demand).

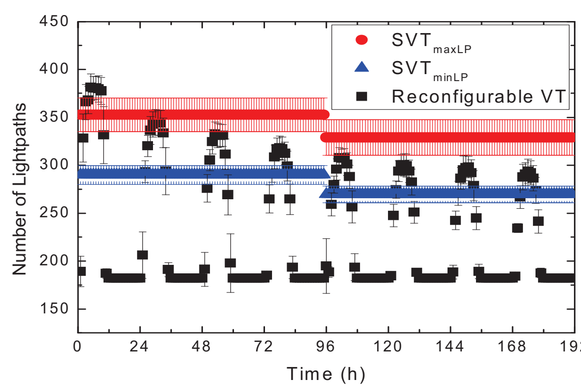

Fig. 6. Evolution of the number of lightpaths of the three sequences of virtual topologies for an average traffic between nodes of 4 Gbps.

The impact of the broken cable is shown at the 96 hour of simulation. The static virtual topologies reduce the number of lightpaths established and reroute the traffic through other established lightpaths. However, the CONGA-VTD reconfiguration mechanism adapts the network for the new conditions and it continues learning and decreasing the number of lightpaths required while satisfying the traffic demand.

B. Performance evolution with different average traffic between nodes

We have also analyzed the impact of different average traffic loads between nodes (from 3.5 Gbps to 6 Gbps) in terms of PLR, OPEX and number of lightpaths established in the virtual topologies.

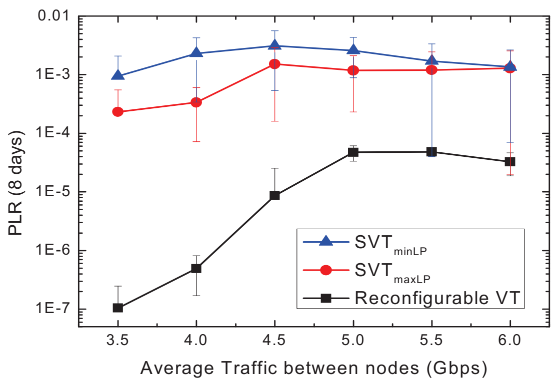

Fig. 7. PLR along 8 simulated days for different avarage traffic between nodes.

In Fig. 7, the average PLR along 8 days (i.e., 192 hours) are shown. It is important to remark that static virtual topologies do not produce losses the first 96 hours. When a cable fails, the static virtual topologies are unable to successfully recover all affected traffic, thus causing a non-zero PLR. However, by means of reconfiguration, the only traffic losses (along the 8 days) are due to the instability during the transition period from one virtual topology to the other. Obviously, the losses in the static scenario could be reduced or even avoided but at the expense of augmenting the overprovisioning and thus costs.

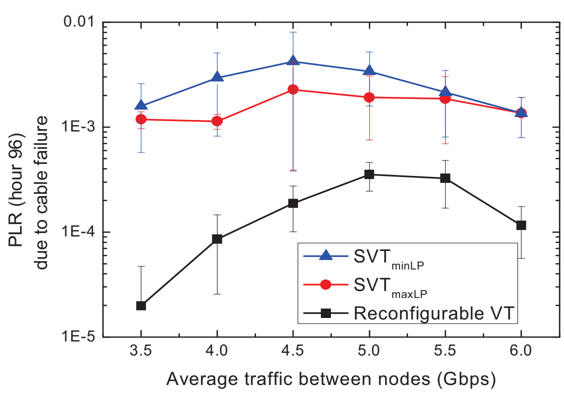

Fig. 8. PLR during the hour 96 when a cable is broken.

In order to evaluate the performance of the three alternatives in the event of a cable failure, the PLR in the hour after the cable break, i.e., hour 96, is shown in Fig. 8. As shown in that graph, the reconfigurable network is also able to reduce the PLR in such critical moments.

After showing that the reconfiguration process can improve the PLR of the network, Figs. 9 and 10 show a comparison in terms of OPEX and the number of lightpaths established (which is related with the number of resources in operation), respectively.

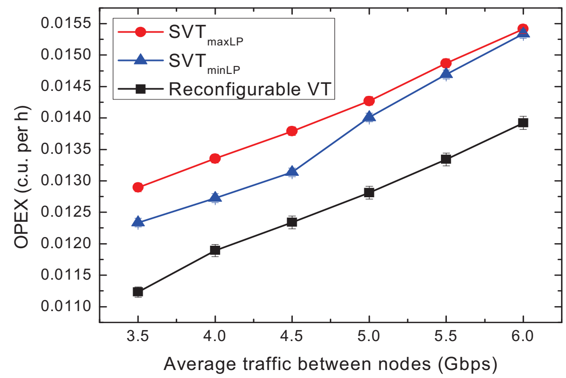

Fig. 9. OPEX per hour for different avarage traffic between nodes.

In Fig. 9, we have compared the reconfigurable option using CONGA-VTD (in black color) with the two static WRONs (red and blue colors) in terms of OPEX. This figure shows the average OPEX per hour along the 8 simulation days. Again, a cable fails at hour 96. The OPEX improvement can be quantified from 6% to 13% for the average traffic rates analyzed. Hence, the use of a reconfigurable network leads to significant cost savings (and also to significant energy reduction). Moreover, as previously mentioned, in order to ensure that the static scenario is able to deal with cable failures without significant losses, it should be designed with additional overprovisioning to that considered here, which would further increase the costs.

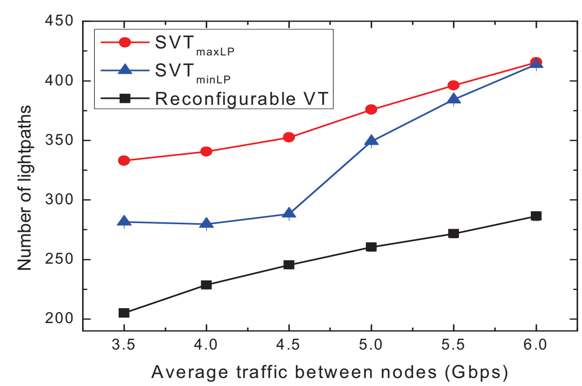

Fig. 10. Average number of lightpaths for different average traffic between nodes.

Fig. 10 shows the mean number of lightpaths established with the three options. The reconfigurable network requires less number of lightpaths established (and therefore resources) to carry the offered traffic load. The reduction is more than 22% when the average traffic load is 3.5 Gbps and more than 25% when the load is 6 Gbps, when compared with SVT_{minLP}, i.e., the less favorable case. It is important to remark that the resources that are not used by the virtual topology can be employed to increase the performance of the overall network as they can be used by other services (for example, the establishment of lightpaths on demand). As a conclusion, the reconfiguration of the virtual topology (when it is properly done) is a useful technique as it reduces the OPEX and the number of resources in operation while maintaining the PLR under an assumable value. Moreover, thanks to the reconfiguration, the network can react against cable failures without the necessity of increasing the number of resources in the network (to establish backup facilities), and therefore reducing the CAPEX and OPEX.

IV. CONCLUSION

In this paper, we have presented a new virtual topology reconfiguration policy for CHRON in order to reduce PLR, save OPEX and minimize the number of resources in operation.

Two CHRON modules are involved in this reconfiguration process: the NPDM and the VTD. CONGA-VTD is presented as the method to be used in the VTD module. It is a multiobjective genetic algorithm to design the virtual topologies minimizing the congestion, the OPEX and the number of lightpaths changed from the current virtual topology to the new one. The Reconfiguration Decision System, which is part of NPDM, decides when the reconfiguration should take place by considering the PLR and the OPEX of each alternative.

Both modules implement cognitive techniques in order to increase the performance of the network. NPDM implements traffic forecasting while CONGA-VTD uses a Knowledge Base to design better virtual topologies.

The simulation results show that the use of reconfiguration (when utilizing the new techniques) improves the performance of the network as it reduces both the OPEX and the number of resources in operation while keeping the PLR under an assumable value.

Moreover, the reconfiguration policy has also shown a good performance when it faces cable failures. The reconfigurable network is able to adapt its virtual topology to the new conditions maintaining low values of PLR and it avoids significantly overprovisioning the network with backup resources and, thus, it reduces CAPEX and OPEX.

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