Minimizing Cost of Hierarchical OTN Traffic Grooming Boards in Mesh Networks

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***Abstract*—The continuous traffic growth experienced in telecom networks pushes network operators to constantly investigate new solutions to deploy scalable and cost-effective network architectures, especially in the metro segment. These solutions should also ensure backward compatibility with existing network architectures. A cost-effective technical solution for today's metro networks consists in optimizing the deployment cost of hierarchical traffic-grooming boards while considering a mix of coherent (typically 100 Gbps) and non-coherent (typically 10 Gbps) transmission technologies. In this study, we consider metro regional networks composed of interconnected filterless rings, and we investigate how to minimize the joint cost of stacked Optical Transport Network (OTN) traffic-grooming boards, coherent and non-coherent transponders and interfaces, and Dispersion Compensation Modules (DCM). We propose a novel optimization approach based on Genetic Algorithms to effectively solve the associated grooming problem and compare its performance to baseline strategies, showing that we can reach up to 79% cost savings in terms of the total cost of deployed equipment.**

***Index Terms*—OTN hierarchical boards, Traffic grooming, Coherent and non-coherent transmission technology**

I. INTRODUCTION

To cope with the high capacity demand brought by 5G-and-beyond applications and keep network costs to minimum, novel solution to deploy low-cost network architectures must be considered. From an operator's point of view, the objective is to serve all traffic demands while minimizing cost and ensure that novel technologies are compatible with currently deployed technologies. In particular, recently-adopted coherent technologies allow to support high-capacity demands and enable the tuning of various configuration parameters to achieve better network performance, but at the expense of increased network design complexity. On the other hand, several network segments, such as metro-access and metro-regional networks, must still accommodate a large base of legacy 10G non-coherent lightpaths [1]. Hence, a hierarchical node architecture supporting co-existing coherent (100G/200G) and non-coherent (10G) transmission technologies is required for cost-efficient network planning [9]. In this paper, we investigate the optimization problem arising when deploying a metro network with hierarchical grooming nodes. Specifically, we optimize the deployment of hierarchical Optical Transport Network (OTN) traffic-grooming boards at the electrical layer and coherent and non-coherent transponders and lightpath establishment at the optical layer. Performing traffic grooming which considers such hierarchical node structure equipped with various stacked OTN boards and the co-existence of coherent and non-coherent transmission technologies (100G/200G and 10G lightpaths), significantly increases problem complexity with respect to traditional traffic grooming problems in optical networks [2]. Moreover, we consider a filterless node architecture at the optical layer, which further increase problem complexity. The main benefits brought by the filterless nodes are the low CapEx costs, low power consumption and footprint, and low/medium initial system capacity with the ability to grow upon need. In particular, the low CapEx is due to the replacement of costly WSSs with passive splitters and combiners. The low power consumption is due to the low power requirements of passive equipment and the ability to increase the supported capacity due to a modular add/drop section at the node level and supporting traffic grooming to ensure a capacity increase to cope with added traffic. In [9], we proposed a novel approach that minimizes equipment cost of OTN traffic grooming boards and considers both mixed coherent (100G/200G) and non-coherent (10G) transmission technologies in filterless horseshoe (ring) networks. This paper aims to minimize the deployed equipment cost of OTN traffic grooming boards in mesh networks (i.e., interconnected rings), which is a much more complex problem. In fact, especially in networks with high number of nodes, the combinatorial complexity of the optimization problem that jointly solves routing and grooming for a large matrix of connection requests makes existing solutions for the Routing, Grooming, and Wavelength Assignment (RGWA) either unscalable (as for Integer Linear Programming) or uneffective (as for traditional heuristics and meta-heuristics) in mesh networks. Hence, in this study we propose a new optimization approach based on Genetic Algorithms (GA). With respect to a baseline application of GA, we consider pruning the paths and the number of opportunities for intermediate grooming to obtain a flexible tool whose complexity adapts to the problem size. The newly-proposed GA is tested over realistic metro networks organized as interconnected rings with filterless two-degree nodes in the rings and filtered multi-degree nodes equipped with Wavelength Selective Switches (WSSs) interconnecting the rings. The paper is organized in five sections: Section II contextualizes our work with respect to the rich literature on traffic grooming in optical networks. In Section III, we model the problem of minimizing OTN equipment deployment costs in mesh networks, and we introduce the approaches to solve the problem. In Section IV, we describe case studies and report numerical results. Section V concludes our work.

II. RELATED WORKS

Traffic-grooming in optical networks is a well-investigated topic [2], [3]. The authors in [4]–[7] minimized the total add/drop multiplexers (ADM) cost in SONET/WDM ring topologies by considering the traditional traffic grooming. In [8], the authors proposed an ILP model and a simulated-annealing heuristic to minimize the number ADMs number in SONET rings. Ref. [8] showed that an ADM is placed in source and destination if the connection type is single-hop and if the connection type is multi-hop, as many ADMs can be added in a hub node. In [10], the authors had the objective of improving network throughput. They studied the node structure for a WDM mesh network with traffic grooming capability and provided a formulation of the traffic grooming problem, and also proposed some fast heuristics. In [11], the authors considered traffic grooming in combination with traffic routing and wavelength assignment to minimize the total number of transponders required in the network. Ref. [12] introduced a generic graph model for dynamic traffic grooming in WDM mesh networks. The authors in [13] investigated the problem of efficiently provisioning connections of different bandwidth granularities in a heterogeneous WDM mesh network through dynamic traffic grooming schemes under traffic engineering principles. None of these previous works has considered the fact that practical optical network deployments often require to devise a hierarchical node architecture composed of stacked OTN boards. In our previous work [9], for the first time, we investigated the traffic grooming problem considering the fact that hierarchy of OTN grooming boards that allow the joint support of non-coherent (10G) and coherent (100G/200G) must be also optimized, as significant cost savings can be achieved by properly selecting only the necessary amount of grooming boards. But the work in [9] limited the analysis to ring (horseshoe) topologies. Compared to [9], in this paper, we investigate the problem of hierarchical traffic grooming in mesh networks. As mesh networks are characterized by a high number of nodes, the number of possible combinations to perform traffic-grooming and establishing lightpaths are exponentially higher compared to a ring/horseshoe and require novel scalable optimization solutions.

III. MINIMIZING COST OF HIERARCHICAL OTN TRAFFIC GROOMING BOARDS IN MESH NERWORKS

A. Problem statement

The problem of minimizing equipment cost in mesh networks while deploying hierarchical OTN traffic grooming boards (called minOTN) can be summarized as follows: **Given** a mesh network topology, a set of traffic requests, a set of hierarchical OTN traffic grooming boards and interfaces, **decide** the deployment of OTN boards and interfaces, perform traffic grooming, and establish coherent and non-coherent lightpaths with the **objective** of minimizing the total cost of deployed equipment.

B. Grooming-node modeling

The hierarchical structure of the node (summarized in Fig.1) is composed of up to three stacked OTN boards: OTU2-ADM, OTU4-ADM, OTU-TPD. Each node may be equipped with a pair of OTU2-ADM, OTU4-ADM, and OTU-TPD boards. If the node is two-degree, we assume a filterless structure without WSSs, while for a multi-degree node, we assume it is equipped with WSS. OTU4-ADM and OTU-TPD must be deployed in pairs, while OTU2-ADM can be deployed either as a single board or in pairs. Each OTU2-ADM supports add/drop and performs multiplexing, and it has ten access interfaces, each with a maximum capacity of 10 Gbit/s, allowing clients to connect directly to the board. The access interfaces support various types of client signals such as SDH (i.e., STM1, STM4, STM16, STM64), Ethernet (i.e., 1GbE, 10GbE), and OTN (i.e., OTU1). Each OTU2-ADM board has four Small Form-factor Pluggable (SFP) interfaces that can be used as a 10 Gbit/s OTN point-to-point (p2p) line interface connecting to OTU4-ADM or a 10 Gbit/s OTN optical interface connecting to ROADM and capable of establishing a non-coherent 10G lightpath. If a 10G lightpath is established, a DCM on each link and a channel filter at the receiver side should be placed. The OTU2-ADM board performs traffic grooming and aggregates clients' traffic into OTU2 signals sent to ROADM over non-coherent lightpaths or OTU4-ADM over black and white line connections. OTU4-ADM performs add/drop procedure and multiplexing, and various types of clients can connect to OTU4-ADM boards through ten 10 Gbit/s access interfaces. Moreover, each OTU4-ADM board can receive/send traffic from/to OTU2-ADM via its four 10 Gbit/s line interfaces. OTU4-ADM can groom the traffic of directly connected clients and OTU2-ADM into an OTU4 signal at the p2p line interface connected to an OTU-TPD board. Two OTU4-ADM boards can be connected as a pair and exchange traffic through a p2p interface with 100 Gbit/s capacity. An OTU-TPD board provides one OTN optical interface for at most two OTU4-ADM boards. OTU-TPD boards have two p2p line interfaces, each with 100 Gbit/s capacity, enabling the board to receive/send two OTU4 signals from/to different OTU4-ADM boards. In addition, these two interfaces can act as access interfaces enabling clients with 100 Gbit/s traffic to connect. An OTU-TPD has a colored output interface connected to a ROADM and establishes a coherent 100G/200G lightpath. The OTU-TPD board can aggregate clients/OTU4-ADM traffic into the established coherent lightpath.

C. MinOTN for mesh networks

We solved the minOTN problem for mesh networks composed by interconnected filterless rings by developing a new optimization approach based on GAs. We initially define the structure of chromosomes, gene clusters, and genes. Each chromosome is built by multiple gene clusters. The number of gene clusters is as many as traffic requests. For each traffic

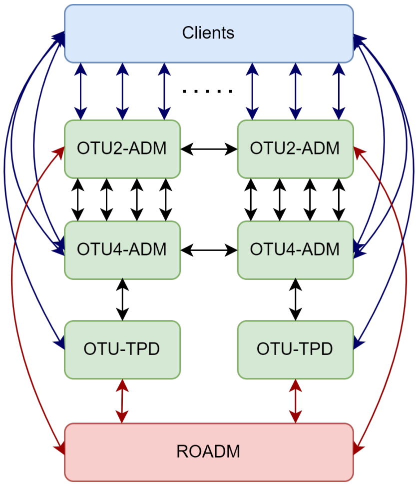

Fig. 1. Node structure

request, all the candidate paths between its node pairs are calculated. Therefore, each gene cluster representing a traffic request is built by multiple genes, and each gene corresponds to a calculated candidate path. Figure 2 shows the structure of the chromosome, gene clusters, and genes. In each gene cluster, only one gene can be selected, and the value of it is set to one. In networks with a high number of nodes, the number of genes is high since the number of paths is too high. Therefore, we need to fine-tune the parameters of GA to ensure a cost-efficient solution. The number of the calculated candidate paths for each traffic request in mesh networks increases exponentially with number of intermediate nodes. Moreover, a traffic request can be dropped in one or in several intermediate nodes to groom with other traffic requests. Therefore, each connection request has many choices for routing and grooming and the GA needs to be fine-tuned to provide a cost-efficient solution in a reasonable time. We propose to constrain the paths based on some specific rules instead of calculating all possible paths. In particular, we jointly reduce both *i)* the number of paths considered (k-shortest paths) and *ii)* the number of add/drop nodes along the shortest path (m add/drop nodes).

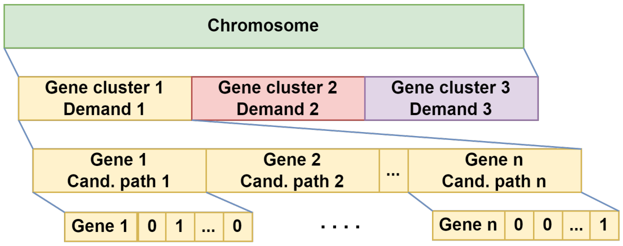

Fig. 2. GA structure

1) An adaptive GA algorithm for minOTN: To optimally solve the minOTN problem, we propose a GA-based strategy in which options for routing and grooming are limited such that the number of genes in the GA solution can be capped. In particular, for routing, we consider k shortest paths, and for grooming we limit the number of m add/drop (A&D) nodes where a lightpath can be dropped and added again. The values of k and m can be chosen to set the level complexity suitable depending on problem size. For sake of clarity in the result section we consider two cases:

a) Case-1: GA-Shortest Hop Count (GA-SHC): In this scenario, we do not limit m and hence we consider the possibility of performing traffic grooming in each node. Figure 3a shows an example of a 5-node mesh network of interconnected rings and the 3-shortest paths with minimum number of hops for a connection request between node 3 and node 4. The green path is a direct path from source to destination. The blue and red paths have intermediate nodes and can go to the destination with or without A&D.

b) Case-2: GA-Shortest Hop Count-Constrained Grooming (GA-SHC-CG): In this scenario, we first calculate the k-shortest paths with minimum number of hops. We know in each path there are at most $2^{(n)}$ A&D combinations, where "n" is the number of intermediate nodes. Therefore, limiting the number of A&D reduces the number of paths, and this means a shorter string of genes for each gene cluster (traffic request). As an example, if the k-shortest path is calculated with minimum hop count, and the number of A&D (m) equals 1, the candidate paths having more than 1 A&D are ignored, and the ones with A&D less or equal than 1 will be selected. Figure 3a shows the calculated candidate paths based on GA-SHC scenario. There is a connection request between node 3 and node 4. The green path connects the source to the destination directly. The blue and red paths pass through intermediate nodes. Considering the red path based on GA-SHC-CG $m = 1$, it can go directly to the destination or be dropped in one of the intermediate nodes (Fig. 3b,3c), and the case that it is dropped in both intermediate nodes is ignored (Fig. 3d).

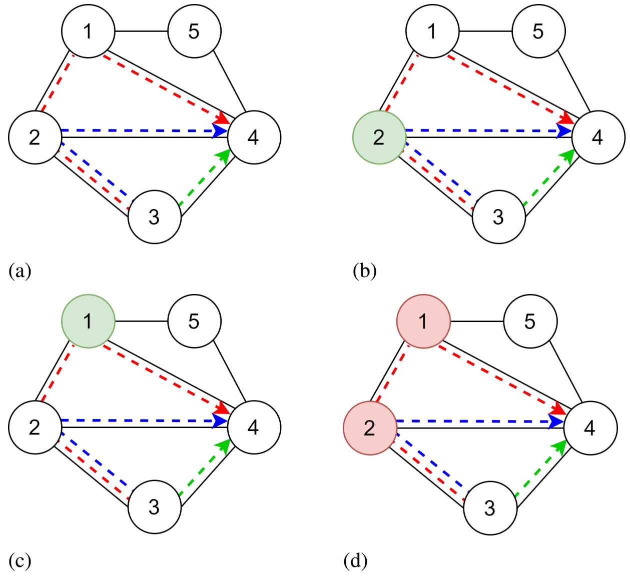

Fig. 3. The GA-SHC and GA-SHC-CG scenarios. The green path is a direct and there is no A&D in it. The red path a) has no A&D b,c) has one A&D in green nodes d) has 2 A&D, so it is ignored.

D. Two baselines: Constrained Ring Routing (CRR) and Omnibus (OB)

In addition to GA-SHC and GA-SHC-CG in which the number of paths is limited based on k-shortest path, we consider two real-world baseline approaches: *i)* GA-CRR and *ii)* Omnibus (OB).

1) GA with Constrained Ring Routing (GA-CRR): in this approach, we also leverage GA, but we employ a conceptually-baseline approach that first determines how many rings the network has and then determines the connection request's source-destination pair. The source-destination pair may belong to same ring or different rings. Therefore, we define two cases: 1) intra-ring traffic and 2) inter-ring traffic. In case of intra-ring, the source-destination pair of traffic request is in one ring and traffic must be routed through the same ring in which its source-destination pair is located. If the traffic request is inter-ring, the source-destination pair of traffic request is in different rings and traffic should be routed through the combination of rings in which the source-destination pair is located. Therefore, each traffic request should be routed through a ring or combination of rings in which its node pairs are located.

Figure 4 shows an example of the 3-ring network. The network has three separate rings (ring 1, ring 2, ring 3) and four combined rings (ring 1-2, ring 2-3, ring 1-3, and ring 1-2-3). If node pairs of the connection request are in ring 1 (intra-ring traffic), the traffic is routed through the calculated candidate paths considered only in ring 1. If the connection request's source is in ring 1 and its destination is in ring 3 (inter-ring traffic), the connection request is routed through calculated candidate paths considered ring 1 and ring 3 and cannot be routed through candidate paths that consider other rings, e.g., ring 2 or ring 1-2. If a traffic request's node pairs are shared among two or more rings, the combination will be selected that considers lower numbers of nodes in case the routing through a combination is feasible. For example, a traffic request between nodes 2 to 4 can be routed through the paths shown in Fig. 4. There are four candidate paths for the traffic request (blue, green, red and yellow paths). Each candidate path can be dropped in one or several nodes for traffic grooming. There are 2^n A&D possibility for a candidate path. Based on the GA-CRR approach, the traffic request can be routed through ring2, ring3, and ring2-3. If there are multiple routing choices, the ring with the minimum number of nodes, in this case ring 2 or ring 3, is selected.

2) Omnibus (OB): is a baseline approach which is used to provide a commonly-used solution for minOTN problem in today's real-world deployments [9]. In this approach, a traffic request is dropped in all intermediate neighbor nodes between its node pairs to perform traffic grooming in each node, by establishing 100G lightpaths between neighbor nodes. Figure 5 illustrates an example of OB in 3-node network. The red paths show the established lightpath between neighbor nodes. In each node, the connection request drops and can groom with other connection requests and with a new lightpath goes to the next neighbor node, or it can drop in a node and without grooming can pass the node and continue to the next neighbor node with a new lightpath.

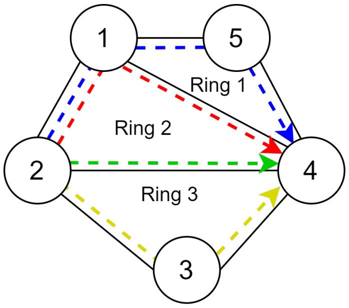

Fig. 4. GA-CRR: the traffic request routed through the rings in which its node pairs are located

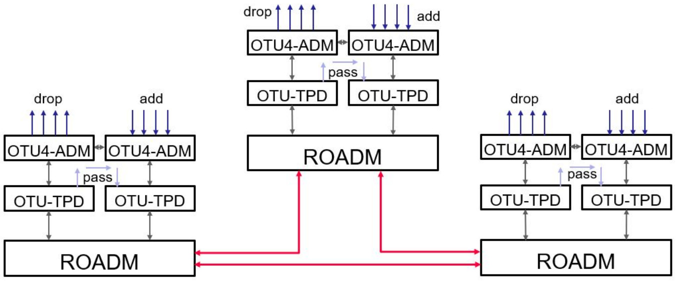

Fig. 5. Omnibus (OB)

IV. NUMERICAL RESULTS

In this section, we show numerical results considering two real mesh networks of interconnected rings and compare the results of OB, GA-CRR, and GA-SHC/GA-SHC-CG scenarios. The 12-node mesh network serves a total traffic of 1 Tbps and the 39-node network 2 Tbps. The types of connection requests are 1 Gbps, 10 Gbps, and 100 Gbps. In this section, first, we introduce the cost model of OTN boards and interfaces. Second, we validate GA performance by solving the problem for a 5-node filterless horseshoe network and comparing its performance to an ILP model. Third, we report the results for a 12-node mesh network. Finally, we present the results for a 39-node mesh network considering OB, GA-CRR, and GA-SHC/GA-SHC-CG. We experimented with the GA-SHC/GA-SHC-CG averaging results over 20 times runs. Our industry partner has provided the cost model, network topologies, and traffic matrices.

A. Cost model

We use the following cost model with normalized cost values. Figure 6 depicts the cost model and reports equipment costs, i.e., OTN boards and interface costs in cost units (cu). In addition to OTN boards and interfaces costs, if a 10G lightpath is established, a DCM (0.53 cu) on each link (one per direction), a filter (0.37cu) for each OTU2-ADM, and a channel filter (0.43 cu) at the receiver for each 10G lightpath are deployed. We consider common parts cost to represent the cost of a shelf where OTN boards are placed. Each shelf can host a pair of the same type of OTN boards, and if more boards are deployed, the cost is added accordingly.

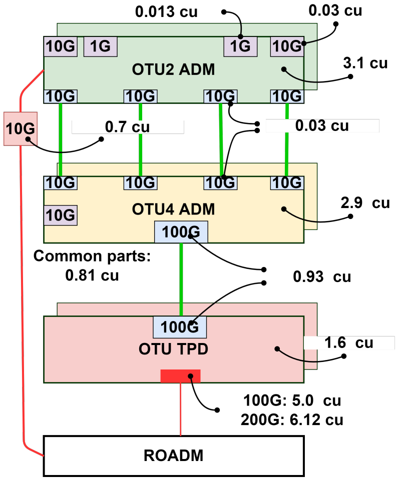

Fig. 6. Cost model

B. GA results validation

We consider a 5-node network topology and two different traffic matrices (TM1 and TM2), which are provided by our industry partner. We solve the problem of minimizing deployed equipment costs with OB, with GA-SHC (with no constraint on k, exploring all possible paths) shown before and with an exact mathematical approach based on Integer Linear Programming (ILP) adapted from [9]. As expected, ILP takes up to 8 hours, even for the 5-node network, showing evident scalability problems. The results for two different traffic matrices, TM1 and TM2, are shown in Table I. For TM1, the GA and ILP have the same cost and, compared to OB, achieve 53% cost savings. For TM2, GA has a 4% gap compared to ILP but still 30% less than OB cost. Therefore, we can confirm that GA performance is validated compared to an optimal solution provided by the ILP, as it reaches similar performance in significantly less time.

TABLE I
NETWORK COST FOR 5-NODE HORSESHOE CONSIDERING TM1 AND TM2

Scenario	TM1-Cost (cu)	TM2-Cost (cu)
ILP	757	1608
GA	757	1678
OB	1499	2399

C. Cost minimization for 12-node network topology

Figure 7 shows the 12-node network topology. We compare the OB, GA-CRR, and GA-SHC (limiting k, but not limiting m) in terms of the total equipment cost, and the results are shown in Table II. Note that we do not limit m as, for a network on medium/small dimension, it is enough to limit k and not m. The GA-SHC results are reported for k equal 2, 3 and 4.

First, let us compare the results of GA-CRR and GA-SHC with OB. For GA-CRR, we split the network into 3 separate and 4 combined rings and route the traffic matrices through these rings. Compared to OB, GA-CRR has around 70% lower cost. The reason is that OB considers A&D in each node while GA-CRR does not enforce the grooming in all intermediate nodes, and it reaches a better cost. Although GA-CRR has a better cost than OB, it is a constraining approach and does not allow GA to explore all the search space. Let us now compare the various approaches to utilize GA to solve the minOTN problem with OB and GA-CRR. The GA-SHC has much lower cost with respect to both OB and GA-CRR. In the GA-SHC scenario, first, we consider $k = 2, 3, 4$ shortest paths in hops number. Increasing the shortest paths number (k) increases the probability of finding a better cost since the GA has more options to choose. Note that as increasing the number of k, the search space becomes larger. It may be that considering k beyond a given number, e.g., $k > 4$, significantly increases the complexity and leads to unpractical runtime of the GA up to 7 hrs. Also, a large search space makes GA to converge harder. Therefore, a trade-off arises between increasing k and decreasing the complexity of the problem. In the 12-node mesh network, over 20 times runs, $k = 4$ achieves a better average cost in a reasonable time compared to GA-CRR and other k values. In the case $k = 4$, there is around 18% and 75% cost saving compared to GA-CRR and OB, respectively. Please note that for GA-SHC scenario the average cost and average time are reported since we ran the simulation 20 times.

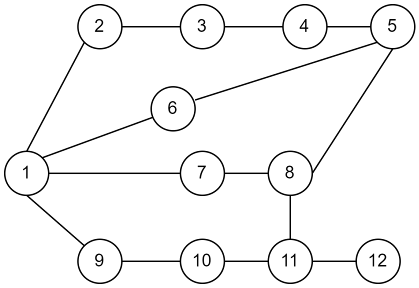

Fig. 7. 12-node mesh topology

TABLE II
EQUIPMENT COST OF 12-NODE MESH NETWORK CONSIDERING OB, CRR, GA-SHC

Scenario	Best cost (cu)	(AVG) Cost (cu)	Time
OB	10646	-	-
GA-CRR	3171	-	2 min
GA-SHC (k=2)	2764	2764	2.1 min
GA-SHC (k=3)	2588	2614	1.1 min
GA-SHC (k=4)	2588	2603	$<$ 1 min

D. Cost minimization for 39-node network topology

As an instance of a large network, we consider a mesh network of interconnected rings containing 39 nodes, as shown in Fig. 8. In Table III, we report the results of GA-SHC/GA-SHC-CG, GA-CRR, and OB. GA-CRR has a 72% lower cost compared to OB since GA-CRR allows to perform grooming in intermediate nodes. Like for 12-node network, the GA-SHC/GA-SHC-CG scenario achieves lower cost compared OB and GA-CRR. For GA-SHC, we considered $k = 2, 3$. We recognize that the case $k = 3$ due to the many candidate paths for each traffic request takes an unpractical long time (more than 8 hours). Therefore, we reduce the candidate path numbers using GA-SHC-CG scenario (by limiting the number of A&D (*m*)). The high number of A&D is one of the main factors of problem complexity. The high value of *m* increases the number of paths, and as a consequence the complexity of GA increases. When the value of *m* is high (particularly in networks with a high number of nodes), the GA convergence is achieved with very long computation times. Therefore, limiting the value *m* can make the problem scalable. For example, if the value *m* is 2, the paths with 0, 1, and 2 A&D are considered, and paths with high number of A&D will be ignored. The number of A&D is varied from 1 to 5 for each *k*. Increasing the number of *m* may result in lower cost as well as increasing the time and complexity. We can see that in Table III increasing *m* does not have a significant impact on cost. The reason is based on the traffic matrix, the best cost can be achieved by $m = 1$, and increasing m just increases the choices of GA. So it is important that the best value of *k* and *m* is identified based on each traffic matrix.

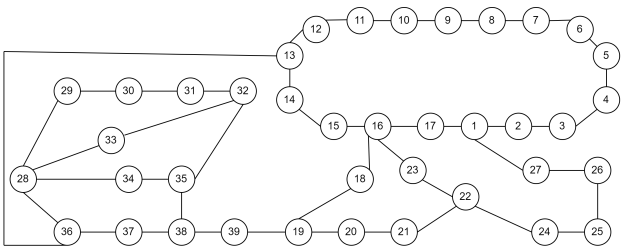

Fig. 8. 39-node mesh topology

TABLE III
EQUIPMENT COST OF 39-NODE MESH NETWORK CONSIDERING OB, GA-CRR, GA-SHC/GA-SHC-CG

Scenario	Best cost (cu)	AVG Cost (cu)	Time
OB	26144	-	-
GA-CRR	7133	-	120 min
GA-SHC (*k*=2)	5706	-	30 min
GA-SHC (*k*=3)	no-solution	-	-
GA-SHC-CG (*k*=2, *m*=1)	5530	5565	< 1 min
GA-SHC-CG (*k*=2, *m*=2)	5530	5592	1.2 min
GA-SHC-CG (*k*=2, *m*=3)	5530	5632	1.7 min
GA-SHC-CG (*k*=2, *m*=4)	5530	5645	2 min
GA-SHC-CG (*k*=2, *m*=5)	5530	5608	2.9 min
GA-SHC-CG (*k*=3, *m*=1)	5474	5512	5.2 min
GA-SHC-CG (*k*=3, *m*=2)	5474	5646	1.3 min
GA-SHC-CG (*k*=3, *m*=3)	5474	5610	3.8 min
GA-SHC-CG (*k*=3, *m*=4)	5474	5615	14 min
GA-SHC-CG (*k*=3, *m*=5)	5474	5920	< 1 min

In the 39-node network, like the 12-node network, the GA-SHC-CG scenarios are ran with over 20 times, and the reported cost and time are averaged. In the case of $k = 2$ and with different *m* values, the best cost is for $k = 2$ and $m = 1$. The cost of $k = 2$ and $m = 1$ achieves cost savings of around 22% and 79% compared to GA-CRR and OB. When $k = 3$, the number of paths becomes too large, and the GA-SHC cannot find the solution. However, by limiting the number of A&D, when $k = 3$, a feasible solution is achieved in practical time. Also in this case, the best cost is achieved when $k = 3$ and $m = 1$, and increasing the value m does not allow to find solution with lower cost, since the best solution is found with one A&D. Compared to $k = 2$ and $m = 1$, $k = 3$ and $m = 1$ achieved a lower cost since the number of shortest paths increased and GA explores a larger search space. The $k = 3$ and $m = 1$ achieves cost savings of around 23% and 79% compared to GA-CRR and OB, respectively.

CONCLUSION AND FUTURE WORKS

In this paper, we solved the problem of optimizing equipment costs for a mesh network composed by interconnected rings with GA. Due to a high number of nodes and considering the stacked OTN traffic grooming boards as well as co-existence of coherent and non-coherent lightpaths, the problem is extremely complex to solve. The main takeaways are as follows:

- In small network instances, restricting the number of paths allows GA to reach a solution, while in larger network instances, restricting the number of paths is not enough, and also the number of add/drop should be limited.
- GA-SHC/GA-SHC-CG routing and grooming strategy with the GA allows to reach the best cost solutions compared to OB and GA-CRR and allows savings up to 79% and 23%, respectively.

As a future work, we plan to investigate an automated solution to select the suitable values of *k* and *m* based on the characteristics of the topology and traffic matrix. We are currently investigating also the application of simulated annealing and reinforcement learning for this problem.

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