Traffic Engineering and Maintenance Domains in WDM Carrier Ethernet Networks

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Abstract— **This paper proposes optimal approaches integrating traffic engineering and protected network connection in Ethernet-over-WDM technology, analyzing to multi-ring and mesh network topologies. It is expected that management can benefit by multi-ring approaches but at a cost of more transceivers required due to its traffic routing constraints. However, study cases with 20 different traffic matrices are performed with 13 nodes in this paper show small transceiver count differences between optimal designs based on both multi-ring and mesh routing in protected and unprotected.**

Keywords-component; Optical Network; Carrier Ethernet; Muli-ring; Protection.

I. Introduction

Due to recent resources offered by telecommunications enterprises, as the Fiber-to-the-Home (FTTH), it has been promoted the increase service provided by Ethernet technologies. However, besides of used in the "last mile", due to the fast price decline, flexibility to install and management, the "Carrier Ethernet" to be more and more attractive to backbone network designs. An appropriate transport platform to support this growing bandwidth demand of Quality of Service-aware multimedia traffic is Wavelength Division Multiplexing (WDM) technique [1]. An important issues discussed in literature, about this technology, is the problem of Capital Expenditure (CAPEX) in network design, that can be reduced with the use of intermediate electronic grooming of traffic demands [2], with the goal of minimize the number of expensive Ethernet Optical Interfaces (EOI). Due to the high capacity of transmission, besides the economical design, a WDM network requires an extra capacity with the purpose of the network survivability.

Recently are founds basically two strategies of routing to backbone transport network, multi-ring and mesh topologies. The multi-ring popularity arises from the natural evolution of the ring technology. The ring-based topologies arose from the inherent management simplicity, and also from their self-healing properties, which allows, for example, restoration time in the presence of network failures in less than 50 ms [3]. Similar carrier-class standard, which is capital to services QoS a whole, has been proposed to carrier Ethernet through the IEEE 802.17 Resilient Packet Ring (RPR) [4]. The multi-ring configuration requires the interconnection of many single rings, which can be realized by single or dual node of interconnection. Dual node interconnection (DNI) is such a powerful means of improving resilience in the network. Due to reasons of the strategy of protection adopted in this article, we will consider only DNI multi-ring.

On the other hand, the mesh architecture takes full advantage from the possibility of exploring all the available routes in the network; thus better capacity exploitation is expected. Moreover, effective restoration techniques can be used to face failures so minimizing the spare capacity used [5].

However, besides CAPEX, the choice between multi-ring and mesh strategy must consider others aspects. A fundamental issue that should be regard is the network management. For instance, consider the carrier Ethernet as transport technology, the network manager deals with set up and tear down connection, signalling in case of failure, etc.

II. Previous work and contributions

The resilience issues of Carrier Ethernet is a fairly recent topic of research (e.g., [6][4][7]). Reviews on IEEE 802.17 standardization and its extension to carrier Ethernet and can be found in [4] and [7]. Based on shortest path heuristic approach over mesh topology, comparison between CAPEX of Ethernet-over-WDM with other competing technologies, such as IP-over-SDH-over-WDM and IP-over-WDM, is presented in [6]. As far as resilience is concerned, simple 1:1 path protection are considered in [6] while [8] applies similar path protection but using more elaborated heuristic approaches to reduce EOI count in Ethernet-over-WDM in mesh networks [8]. RPR extension to multi-ring topologies with dual node interconnection has been recently suggested in [4] and [7] as a means of avoiding single point of failure vulnerability of inter-ring connections. It is clear that, this ring interconnection also benefice the mesh. In addition, it is impossible implement a scheme of protection in a single node interconnection, whether to multi-ring or mesh.

This paper proposes an optimal network design to a project without protection and another with 1+1 protection, called virtual ring (VR). The strategy in order to meet the economic aspect is allowed the electronic processing in every node, realizing traffic grooming, aiming at reducing EOI count.

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Extensive numerical results for a 13-node network bring comparisons between mesh and multi-ring strategies for a total of 20 different traffic matrices.

The proposal presented in this paper tries to address, along with the management and economical aspects, beyond the resilience multi-ring and mesh topologies. The protection strategy analyzed takes a 1+1 approach. This meets the high-speed failure recovery in multiple-ring and mesh environment with minimal resources usage. Load balancing requirements may also be met by the proposed objective function. The design herein is aimed at the minimization of the maximum number of EOI at a given node. This imposes traffic engineering configurations with better distributed load profile than designs aimed at minimal EOI total count. The approaches proposed to solve each instance are based integer linear program (ILP), thus ensuring the optimal solution.

The remaining sections of this paper are organized as follows. With the goal of compare mesh and multi-ring management the Maintenance Domain is briefly described in the next Section. The scheme used to interconnect the rings are described along with routing constraints associated, is presented in the Section IV, where and shows 1+1 unidirectional protection switching. Section V presents the proposed integer linear programming (ILP) models for traffic accommodation with and without protection across the mesh and ring interconnections. This design stage is responsible for the optical configurations in the WDM nodes and assigning the EOIs in the Ethernet Switch. Case studies are performed in Section VI for different traffic growth scenarios. Finally, the major findings of the paper are summarized in Section VII.

III. RING-BASED MAINTENANCE DOMAINS

The 802.1ag - Connectivity Fault Management (CFM), which specifies a basic set of OAM functionalities for carrier Ethernet based networks along with Y.1730 and Y.173 define the concepts of network management. These standards are based on the fact that Ethernet networks often encompass multiple administrative groups, or Maintenance Domains (MD), and they allow a hierarchical multi-domain network model to be used. Therefore, this concept is well suited to managing multi-ring topologies where a two-level hierarchical maintenance domain division can be proposed, i.e., intra-ring and inter-ring, as illustrated in Figure 1.

A MD is an administrative group for the purpose of network management and administration, defined by a set of Network Entities (NE). In Figure 1 a MD encompasses nodes from a ring where Operation Administration and Maintenance (OAM) functions are applied. A MD is terminated by a Maintenance End Point (MEP) at an edge node, as shown in the inter-ring gateway in Figure 1, where OAM messages are inserted and extracted. An MD may have Maintenance Intermediate Points (MIP), which allow measurements to be performed at intermediate points inside a MD. The Operation Support System (OSS) controls the operation of the whole network. Each NE is connected to, controlled by and reports to OSS. In Figure 1 the hierarchical approach proposed makes the managements of NE belonging to a given ring to be supervised by separate OSS. Inter-ring connections will be supervised by a superior layer of OSS while intra-ring NEs are controlled by local OSS. This allows OAM to be performed in more efficient way, not only by reducing management traffic in the network but also by enabling faster fault isolation and more autonomous actions to be taken within rings.

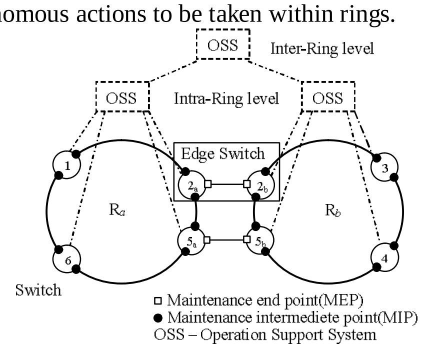

Figure 1. OAM Management Model employed over multi-ring topology.

Since Ethernet permits multipoint-to-multipoint connectivity, OAM functions have to be able to handle such complex scenarios. On a mesh topology, considering the need for n-to-n MD connectivity, defining the ideal number of NEs inside a given MD may be a critical task. A mesh approach can result on a huge OAM traffic crossing the network. On the other hand, the ring topology simplifies this task, once it may define a single MD for each ring, reducing significantly inter-ring OAM traffic. The ring topology also allows better distribution of supervisory load among the whole network. By defining ring-based MDs, a MEP may discover more easily a failure inside the ring, based on the fact that there are only 2 physical paths, allowing the quick isolation of this portion of the network. Once the failure is detected, the MEP may report to its neighbour, for example, only the ring ID where the failure appeared, commanding the other MEPs to avoid this ring for routing its traffic. Moreover, once MEP messages are multicast based, the ring topology reduces inter-ring OAM Continuity Check (CC) and Link Trace (LT) messages, by confining these OAM frames inside a MD.

Nevertheless, all these benefits will depend on the capacity of keeping the intra-ring traffic within the ring in other to be coherent with the management topology. Intra-ring traffic should be confined to the fewest number of intermediate rings. In other words, traffic routing constraints must be imposed when intra and inter ring connections are served by the network. These constraints will reduce the capacity of optimally accommodating the traffic demands over the physical topology available when compared with mesh routing where such restrictions are not applied.

IV. ROUTING IN MULTI-RING NETWORKS

As network topology it was used a 13-node network, shows in Figure 2 (a). In addition, Figure 2 (b) presents the multi-ring interconnections, when this management strategy is considered. The main difference between mesh and multi-ring topology design resides in the routing strategy. In the multi-ring networks, if source and destination nodes belong to the same ring, the path used by this connection must stay confined within the common ring. This connection is classified as intra-ring demand; otherwise, the connection is classified as an inter-ring traffic demand. The constraint imposed for an inter-ring traffic demand is that it should be routed traversing the minimum number of rings. In a mesh network design a given traffic demand can be routed without path constraints.

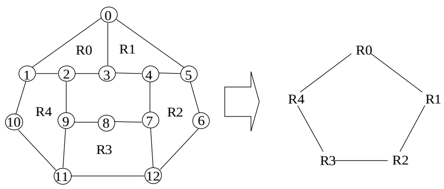

Figure 2. (a) 13-node network topology; (b) auxiliary graph representing the connection among rings.

Yen's Algorithm [9] is employed in order to generate a set with all *R*-shortest paths (hop count) between nodes without the ring-based constraint. Then a sub-set is selected from this large group of paths taking only those meeting the shortest path, on a ring-crossing count basis, over the auxiliary graph. The set with the selected routes meeting the multi-ring routing constraint are given as a pre-computed input parameter to the proposed ILP models in Section V.

V. ILP FORMULATIONS

Let an WDM multi-ring network be represented by a multigraph $G = (N, E, W)$; where N is the set of nodes, E the set of physical links, with $(i,j) \in E$, and W the set of channels (wavelengths) between each connection. The traffic matrix, traf[s][d], defines the traffic demands between a source node s and a destination node d. A link-path approach is here used where routes are pre-computed and $r \in R_{sd}$ represents a route within the set of allowed routes to serve the demand traf[s][d] between a pair of nodes (s,d). The link-path indicator $\delta_{ij,r}^{sd}$ is binary variable, which takes value one whether link (i,j) is used in route r to serve demand (s,d), and zero otherwise. Each link (i,j) can bear a set of W wavelength, and $w \in W$; and finally, the wavelength transmission capacity is limited to C units of traffic for all w.

A. ILP Model for DNI without Protection (DNI-WP)

Traffic can be groomed with the granularity of one unit of traffic. The following notation is used in our mathematical model: X_{ij} is the amount of traffic over connection (i,j); XN_{ij} is the number of wavelengths in a connection between (i,j); and Λ_r^{sd} is the sought optimal traffic engineering outcome, it represents the amount of traffic from s to d using route r.

Objective Function:

As we deals with opaque networks, the number of wavelength in a link (i,j) coincide with number of transceivers at node i used to connect node j. Then, let EOI_{ij} be the number of EOIs at node i used by link ij to connect node j. The objective function is to minimize the network cost and it can be expressed as shown in (1), where the design strategy is to minimize the maximum use of EOIs on a node-basis. Moreover, this kind of Min-Max approach for the objective function may also benefit load balance as previously discussed and limit the size of Electronic Switches in the network.

Objective Function:

$$Min: Max\ \{EOI_{ij}\} \tag{1}$$

Constraints:

$$XN_{ij} \geq \frac{X_{ij}}{C};\ \forall (i,j) \in E \tag{2}$$

$$XN_{ij} \leq EOI_{ij};\ \forall (i,j) \tag{3}$$

$$\sum_r \Lambda_r^{sd} = \text{traf}[s][d];\ \forall (s,d) \tag{4}$$

$$\sum_{sd}\sum_r \delta_{ij,r}^{sd} \times \Lambda_r^{sd} = X_{ij};\ r \in R_{sd},\ \forall (s,d), \text{ and } \forall (i,j) \in E \tag{5}$$

The first constraint (2) states the minimum number of channels needed, based on the full wavelength capacity C, according to the amount of traffic crossing connection (i,j). The second constraint (3) limits the number of EOIs at node i. Constraint (4) ensures that traffic demand from s to d, over all routes, equals the traffic demand matrix. Finally, (5) is a traffic grooming constraint. It shows that the sum of demands passing through connection (i,j) must match X_{ij}.

The model with redundancy of connections, called VR, can be easily implemented using an additional variable for each demand. DNI-WP formulation will be used as baselines for next model.

B. ILP Model for DNI with VR Protection (DNI-VR)

The DNI architecture under VR redundancy is here presented [10]. In this model, new variables should be added in order to distinguish between working and protection traffic along the network. ΛB_r^{sd} is a binary variable indicating the use of route r as working-path by demand (s,d). It takes one when route r is used to serve demand (s,d), and zero otherwise; P_r^{sd} is the amount of traffic from s to d, using route r, in a backup-path; finally, PB_r^{sd} is a binary variable indicating the use of route r, as a backup-path by demand (s,d), it receives one when route r is used to fulfill demand (s,d), and zero otherwise. Consider that work and backup path must be node-disjoint.

Objective Function: The same used in DNI-WP (see (1))

Constraints: The constraints (2), (3), and (4) also are employed in this model. The following additional constraints define the model DNI-VR.

$$\text{traf}[s][d] \times \Lambda B_r^{sd} \geq \Lambda_r^{sd},\ \forall (s,d) \tag{6}$$

$$\text{traf}[s][d] \times PB_r^{sd} \geq P_r^{sd},\ \forall (s,d) \tag{7}$$

$$\Lambda B_r^{sd} + \sum_t PB_t^{sd} \leq 1,\ r,t \in R_{sd} \text{ where } r,t \text{ are disjoint} \tag{8}$$

$$\sum_{sd}\sum_{r}\delta^{sd}_{ij,r}\times\left(\Lambda^{sd}_{r}+P^{sd}_{r}\right)=X_{ij},\ \forall (s,d) \text{ and } r \in R_{sd} \quad (9)$$

$$\sum_{r}P^{sd}_{r}=\text{traf}\left[s\right]\!\left[d\right],\ \forall (s,d) \quad (10)$$

Constraint (6) is used to establish the relation between variables ΛB^{sd}_{r} and Λ^{sd}_{r} . In addition, it also ensures that Λ^{sd}_{r} will never exceed its traffic demand. Constraint (7) is analogous to (6), however for the backup-path. Constraint (8) ensures that the working-path and the backup-path, used to meet demand (*s*,*d*), are disjoint paths. Constraint (9) defines that the sum of work and protection demands passing through connection (*i*,*j*) must equal X_{ij}. Finally, constraint (10) is analogous to (4), however to ensure that the traffic demand from *s* to *d*, over all routes, equals the traffic demand matrix for protection purposes, respectively.

VI. Results

This section presents numerical results for the WDM optical network considering a 13-node network, with the physical topology described in Figure 2 (a), for the connections with and without redundancy, i.e., VR and WP, respectively. Wavelength transport capacity is set at 64 and unitary granularity. This is equivalent to STM-64, with STM-16 granularity, or approximately 10 Gigabit and 155.52Mbps, respectively, to Ethernet case. The CPLEX Linear Optimizer 9.0 [11] is used to solve the ILP formulations. The experiments were run on a Pentium IV 2.0GHz processor.

Traffic instances are composed of heavy-loaded and asymmetric traffic matrices for full-mesh logical topology. Extensive tests with a total of 20 different traffic matrices are performed. On average, each traffic instance takes below 1 minutes in pre-processing phase (the entire set of paths R is computed), 2 minutes for solving optimal on protection network design (WP), and 4 minutes for (VR). Larger networks can be solved by limiting the *R*-routes found by Yen´s Algorithm since it is very unlikely that the optimization process will make use of extremely long routes. A 26-node network composed of 7 rings has been solved in 10 minutes (each model) simply by limiting *R* to 50 routes for each (*s*,*d*).

Scenarios with growing traffic loads help network designers to foresee the impact of increasing demands over transport network equipment. The strategy used in this paper is to generate random traffic demands with maximum values bounded by integer numbers that are multiples of L_{intra} (for intra-ring traffic) and L_{inter} (for inter-ring traffic). Tunnels demands are multiples of 16 units of traffic (2.5 Gbps). Then the amount of traffic between each pair of nodes is an integer randomly picked from a set {1, …, L_{intra}}, for intra-ring, or {1, …, L_{inter}} for inter-ring demands multiplied by 16. The growing demand traffic scenario is then easily produced by increasing either L_{intra} or L_{inter}. In Figures 3 and 4 the abscissa uses the notation L_{intra}/L_{inter} to identify the upper limits used for both L_{intra} and L_{inter}. For instance, in Figure 4 for abscissa 6/1 each inter-ring demand may assume 16, 32, 48, 64, 80, or 96 units of traffic while an intra-ring demand assume 16 units of traffic (16 x 1). Therefore, the mean traffic grows as *L* (L_{intra} or L_{inter}) increases according to $\mu(L)=16x\sum_{\alpha=1}^{L}\frac{\alpha}{L}$. Note that traffic uncertainty and imbalances in the traffic matrices are also dependent on *L* as higher statistical moments follow increases in *L*. To the mesh network design it was consider the same traffic demands, however these demands were routed using mesh topology strategy.

A. 6.1. EOI count: VR versus WP

Figure 3 shows how the growth of L_{inter} influences the number of EOIs needed for VR and WP considering the objective function and total number of EOIs obtained using this objective function. Here the intra-ring demand is fixed at 16 units of traffic and optimal results for growing inter-ring traffic are found for 10 different traffic instances considering that intra-ring traffic remains constant. The ordinate in Figure 3 (a) brings the outcomes of the objective function, while in Figure 3 (b) it represents the total number of EOIs that has to be deployed in order to meet the whole demand in each traffic instance.

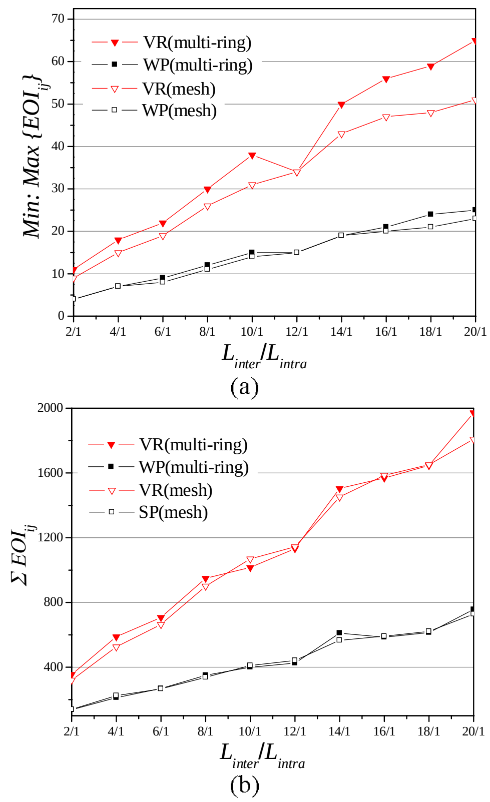

Figure 3. (a) Min:Max {EOIij} and (b) ΣEOIij vs. 10 different inter-ring growing traffic loads, over a 13-node network for VR and WP models.

As inter-ring demands require many of hops across the network, it is expected that the network cost, i.e., EOI count, should be steeply increased with L_{inter} growth. In Figure 4 (a) and (b) the WP shows a no significant difference between mesh and multi-ring. It happened due to multi-ring routing strategy and the fact of WP assign only an optimal route to each demand. It is clear that VR require more than double of resources than WP, as WP achieve an optimal no protection design and the demands of backup needs to be assigned in disjoint path, it is hardly to find a backup path with at least the same cost of work path. It last outcome can be found in Figures 3 and 4. The min-max results obtained by VR, as presented in Figure 3 (a), indicates that the mesh strategy is a better than multi-ring. In addition, comparing VR in Figure 3 (a) and (b), we conclude that to inter-ring traffic increase, mesh strategy achieve a more balanced network than multi-ring design. It idea is supported by fact that total network cost in both scenarios is similar and the worst case mesh design is smaller.

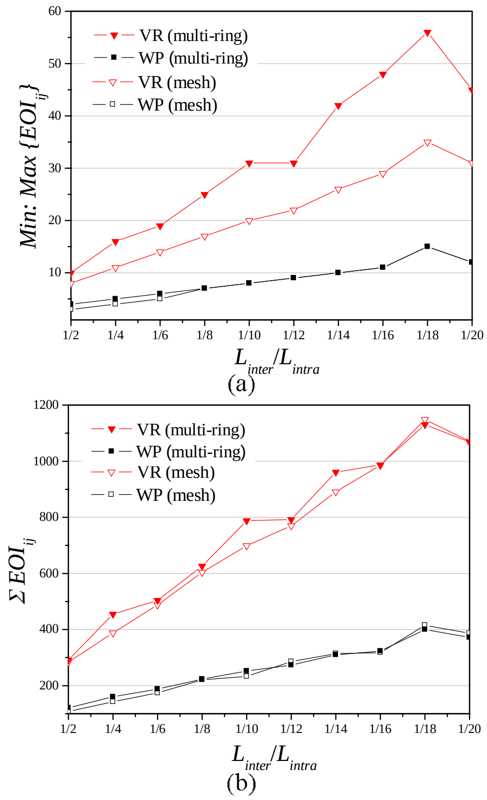

Figure 4. (a) Min:Max {EOIij} and (b) ΣEOIij vs. 10 different intra-ring increasing traffic loads over a 13-node network for WP and VR models.

Figure 4 brings a complementary traffic scenario to the one presented in Figure 3: growing intra-ring traffic and static inter-ring demands. Looking into results for WP design analogous the growth of EOI count seen in Figure 3 also appears in Figure 4, nevertheless in a smaller progression due to kind of traffic increase. As the intra-ring demands must be confined in a unique ring, considering VR protection, the intra-ring traffic increase presents a great difference between the two strategies of routing. Note that, in the worst case, VR with multi-ring protection reach approximated 50% more EOIs than mesh routing. For instance, to 1/4 the VR (mesh) reached 11 EOIs while VR(multi-ring) reached 16 EOIs, more over analogous difference can observed in 1/10, 1/16, etc. Nonetheless, this difference becomes considerable smaller when analysed the total number of EOIs.

VII. Conclusion

Novel optimal approaches to traffic grooming in mesh and multi-ring context were proposed for both inter-ring nodes with and without traffic redundancy. The network design without protection is presented as benchmark to measure the cost of 1+1 in different scenarios. Study cases with a total of 20 different traffic matrices were performed over opaque networks with 13 nodes. Traffic growth scenarios were used to compare VR and WP regarding the number of EOIs used in the busiest fiber.

As an important result, it was obtained that the multi-ring routing constraints do not imply in a significant additional cost. However, besides of this expected result, we can measure real cost of 1+1 protect in both routing strategies, multi-ring and mesh. In addition, it was address the consequences of select multi-ring or mesh topology. This choice will influence in management cost and complexity. For future studies, the proposed approaches will regard the management cost and complexity parameters, with the intension of CAPEX and OPEX reduction.

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