Mathematical Programming for Joint Protection/Restoration of IP over DWDM Networks

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Abstract — **A novel joint multilayer restoration scheme for IP-over-DWDM networks is proposed, where the restoration algorithm manages network resources from both the IP layer and the optical layer in a synergistic manner. Since IP router ports are typically more expensive than optical switch ports, the essence of the approach is to attempt to reuse IP service ports or the service wavelengths associated with optical switch ports for restoration rather than reserve additional standby IP ports exclusively for network recovery. This can be done when there are concerted actions between the IP and optical layers. Since in our approach network recovery is performed by joint actions in the IP and optical layers, we compare this to an approach where a node failure is recovered in the IP layer alone with no assistance from the optical layer.**

I. Introduction

To date, most of the restoration studies for multi-layer networks focused on how to coordinate/integrate the restoration functions offered by each individual network layer. The underlying principle of this coordinative multi-layer restoration is, each layer choose the most suitable restoration strategy for that layer, then the "best" coordination of these individual recovery mechanisms (known as escalation strategies [1]) are explored. It is very possible that this kind of "best/good" restoration scheme is far from the most efficient recovery scheme, from the entire network point of view. Recent advances in generalized multi-protocol label switching (GMPLS) [2] and the extensive study and understanding of IP-over-optical network architecture, opens up the possibility for coordinated actions across the two networking layers. A novel joint multi-layer restoration scheme for IP-over-DWDM networks has been proposed, where the restoration algorithm manages network resources from both the IP layer and the optical layer in a synergistic manner. For example, a single node failure in the IP layer can be restored by a cost-effective combination of IP and optical layer rerouting. Since IP router ports are typically more expensive than optical switch ports, the essence of this approach is to attempt to reuse IP service ports or the service wavelengths associated with optical switch ports for restoration, rather than reserve additional standby IP ports exclusively for network recovery. This can be done when there are concerted actions between the IP and optical layers.

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II. Mathematical Programming

Mixed integer programming (MIP)-based multi-commodity maximum flow (MCMF) optimization problems are formulated to determine the restoration paths for affected traffic by any single IP network failure (node failure, link failure). The number of wavelengths in each link, the number of IP ports in the higher layer of each node, and the number of smart optical ports at the optical layer are also determined. In this optimization problem, the total facility cost, which includes the link transmission wavelength cost, the IP port cost, as well as the smart optical port cost, is minimized. A set of constraints (the restoration flow balance constraint, the link capacity flow constraint, the IP router port capacity constraint, and the smart optical port capacity constraint) define the formal mathematical specification of the optimization problem. The network topology and the IP traffic demands are given as the inputs of the optimization problem. The results of the MIP model find the global optimal backup paths among all the possible alternative paths for all traffic demands. Under the single failure assumption, the network resources (transmission wavelengths, IP router ports, and smart optical ports) are shared among all end-to-end traffic demands. When a certain number of wavelengths have to be grouped into one fiber along the network links, we originally define the MIP formulation of this restoration with a discrete link cost structure.

III. Main Results

In order to evaluate the benefit of the proposed joint restoration approach, we consider the particular case of single node failures in the IP layer. Since in our approach network recovery is performed by joint actions in the IP and optical layers, we compare this to an approach where a node failure is recovered in the IP layer alone with no assistance from the optical layer. The comparison is the total cost of the two restoration schemes including IP port, optical port and mileage costs. Our case studies for two real-world service-provider networks show that this joint multi-layer restoration scheme is much more cost-effective in all cases for realistic costs of the various components. Further, extensive sensitivity analysis showed that the cost savings are robust even when the assumed costs vary significantly.

References

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