# TWO-LAYER RESTORATION SCHEME FOR IP OVER OPTICAL NETWORKS WITH MPLS

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**Abstract** - Wavelength division multiplexing (WDM) based IP networks will provide capacity for the explosive growth in IP traffic. Network reliability gains importance with the huge volume of traffic carried by such IP-over-WDM networks. Providing survivability at the optical layer is inherently attractive, but raises many questions and challenges, given similar mechanisms already exist at IP layer. The emergence of MPLS and its extension, MPλS, opens up new possibilities for developing simple integrated protection/restoration schemes that can be coordinated at both the IP and optical layers.

This paper first presents an overview of existing MPLS/MPλS recovery mechanisms. Then we propose a joint two-layer recovery scheme for IP-centric WDM based optical networks where the optical layer will take the recovery actions first and subsequently the upper IP layer initiates its own recovery mechanism, if the optical layer does not restore all affected services. A simulation-based analysis shows the benefits of the proposed two-layer recovery scheme compared to the single layer recovery schemes.

**Keywords** - MPLS, WDM, restoration, protection.

## I. INTRODUCTION

With the explosive growth of the number of hosts on the Internet and the resulting traffic per host, Internet traffic is growing exponentially. An unprecedented shift has occurred in traffic pattern from fixed, configured, connection-oriented services (e.g. voice service) to dynamic, connectionless IP services [1]. Although there has been a slowdown in Internet growth over the past years, it is expected that Internet traffic will continue to grow dramatically. WDM technologies are being deployed in the networks, to meet this bandwidth demand. WDM technologies combine multiple signals, each at different carrier wavelengths to increase capacity. Lightpaths are set up to provide end-to-end connections between optical cross-connects (OXCs).

IP-over-WDM is a simple example of a multi-layer network, where the IP layer resides above an optical network. The IETF has proposed the Multi-protocol Label Switching (MPLS) technology [2], where packets are forwarded based on the appended labels. MPLS separates the routing decisions and forwarding of the data. Connection-oriented paths – so called label switched paths (LSPs) are set up for connectionless IP packets. There are also current efforts to port MPLS to the photonic domain, resulting in the Multi-protocol Lambda Switching (MPλS) [3]. The wavelength color is regarded as a label and the label switching concept is used to provision wavelength-switched lightpaths.

Modern networks should be designed to be fault tolerant. MPLS offers fast and efficient protection/restoration capability to provide network survivability. This fast protection/restoration capability is also a key feature of the MPλS, inherited from MPLS. Thus each different layer in such a multi-layer network provides its own recovery capability.

In this paper, we will deal with the issue of providing survivability in such IP/WDM networks. A multi-layer strategy is proposed and simulations are performed to compare its performance with other single layer survivability schemes, from both capacity and restoration speed points of view.

The rest of this paper is organized into 5 sections. Section II provides a brief description of the existing protection and restoration schemes. Section III presents the proposed two-layer restoration scheme. Section IV presents simulation results and discussions. This is followed by a conclusion and suggestions of areas where further work can be done in the last section.

## II. SURVIVABILITY OF IP OVER WDM

### *A. Background on Network Survivability*

Some spare capacity is needed for recovering traffic affected by failures. Depending on the different time scales in which the spare capacity is allocated, there are essentially two types of fault-management techniques: protection and restoration. In protection, backup paths are established and spare capacity is reserved for them at the time the working path is set up. In restoration, upon network failure, backup paths are established in real-time while the spare capacity is allocated to them dynamically. Generally, protection may cost more resources, whereas restoration may take longer to restore the connection.

Protection and restoration have traditionally been addressed using two techniques: path switching and link switching. In path switching, traffic is recovered along a new path between source and destination node pairs of each connection that traverses the failed links. Whereas in link switching, traffic is recovered around failed links.

### B. MPLS Recovery Mechanism

The nature of IP implies that it reacts very slowly to network failures and it is not desirable to employ IP layer recovery with MPLS. Therefore, some faster mechanisms for MPLS recovery have been proposed in [4][5].

In an end-to-end path protection scenario [4], a pre-established backup LSP is set up from ingress LSR to egress LSR, which is physically disjoint from the working LSP. This pre-established backup LSP does not require any resources as long as the working LSP has not failed. When the working LSP fails due to the failure of network component, the ingress LSR no longer forwards packets along this LSP, but switches over to the backup LSP.

A similar approach to path protection can be implemented on a link switching base, which is called local protection. A backup LSP only spans a link (or a node) to protect this link (or node) [5]. If a working LSP spans several links, one backup LSP has to be setup for each link in the working LSP respectively, in order to protect the whole working LSP.

A hybrid scheme named local loop-back (also called Fast-Reroute" or "Alternative Path") was also proposed in [5]. It combines the best characteristics of both path and local protection schemes.

Rerouting [4] is essentially a restoration mechanism, since it is based on the real-time establishment of the backup LSP. The LSP is able to get the route of the backup LSP according to the automatically updated routing table after the failures. The main disadvantage of rerouting is that the recovery time can be quite long; inheriting this feature from the IP routing protocol on which it relies. Therefore, some improvements are proposed to minimize the restoration time, such as explicit failure notification that accelerates the failure detection of the LSR and a set of pre-calculated reroutes used to reroute the time-critical traffic. Of course, rerouting has the advantage that it is able to deal with very complicated failure scenarios. In [5] the authors propose a novel rerouting mechanism named Fast Topology-driven Constraint-based Rerouting (FTCR) to mitigate some problems of the original rerouting scheme. The novelty of FTCR is that the first upstream LSR rather than the original LSR is responsible for rerouting.

### C. Recovery in Optical Networks

The optical layer also can provide the resilience. In the IP-over-WDM two layers scenario, the MPLS concept has been extended to the optical domain via MPλS, thus, the MPLS recovery strategies can be adopted in the MPλS context in a straightforward manner [3][6]. But they are restricted to the physical characteristics of optical networks.

The backup lightpath cannot be established without allocating resources. A wavelength is consumed by the backup lightpath once it is established. This leads to dedicated protection in the optical domain instead of shared protection in the MPLS domain. Since the number of wavelengths in a single fiber is limited, the problem becomes more critical. Furthermore, since it is currently not economically feasible to place wavelength converters everywhere in the network, the utilization of spare wavelengths is low due to the wavelength continuity constraint. More consideration that should be included in the adoption can be found in [6].

Because rerouting and FTCR do not need to pre-establish a dedicated lightpath, they do not suffer so much from the high capacity cost problem as do the protection mechanisms. But the route of the rerouted lightpath is also constrained by the wavelength continuity problem, if no wavelength converter is available along this backup route. Compared to MPλS protection, MPλS restoration performs much better from a capacity point of view. On the other hand, it is much slower than protection.

## III. JOINT TWO LAYER RESTORATION SCHEME

In this kind of IP-over-WDM network, both the IP and optical layers have some recovery capability, and a single-layer recovery scheme may be deployed in either layer. An important question arises. In which layer should one provide network survivability? An intuitive possibility is to provide resilience in the optical layer, since the recovery actions are performed on the coarsest granularity. Although failures at the physical layer and optical transport equipment failures can be recovered at the IP/MPLS layer as well, in the optical layer a single element failure is treated and fewer recovery actions are taken. In addition, failures do not propagate through multiple layers before triggering any recovery actions. However, the optical layer is not always able to resolve problems caused by a failure that affects a higher layer. For example, when an OXC fails, the optical layer can only recover lightpaths transiting the failed OXC, hence the LSR(s) residing on top of the failed OXC becomes isolated and thus only the IP layer is able to restore all traffic transiting this isolated LSR.

Since the optical layer cannot recover all kinds of failures in the network, the IP layer has no other choice than to take over the recovery job. Though providing resilience at the IP layer can deal with the failures occurring at either IP or optical layer, it suffers from the fact that many recovery actions are needed, due to the finer granularity of the LSPs at the IP layer. Furthermore, a single element failure in the optical layer will result in typically complex secondary failures in the virtual topology. However, the finer granularity also allows the differentiation between individual LSPs, based on their service class with different reliability requirements.

Recovery at either optical or IP layer has its own pros and cons. A more advanced possibility is to provide recovery at both the IP and optical layers, i.e. a multi-layer recovery strategy. This multi-layer survivability strategy has been studied in previous work [7][8]. The initial motivation of the multi-layer strategies is to avoid duplicated survivability functionality at multiple layers that can yield reduced resource utilization and routing instabilities.

With the idea of multi-layer recovery, we propose a novel joint two-layer restoration scheme for MPLS based IP-over-WDM networks. Recovery work is done sequentially in a bottom-up fashion. The recovery starts in the optical layer which is closest to the failures. If the optical layer is unable to restore all the affected traffic, the IP layer takes over the recovery actions.

The spectrum of recovery mechanisms as we mentioned in Section II B and C can be deployed in either layer, i.e. one is free to deploy any of them in any layer of the network, and any combination of recovery technologies in different layers.

Some inter-working mechanisms exist for handing over the responsibility for recovery from one layer to another layer [8]. One is called hold-off timer. A timer is set at the moment the optical layer starts attempting to restore the traffic and the IP layer takes over the recovery when this hold-off timer times out. Or alternatively, in the recovery token method, the optical layer sends the explicit recovery token to trigger the IP layer recovery.

In our study, we are more interested in deploying rerouting (i.e. restoration) in both the IP and optical layers, since rerouting, especially optical rerouting is very efficient from capacity and cost points of view. Some spare wavelengths are reserved which provision spare capacity to the optical layer used by rerouting. Upon receiving the failure notification message, the optical layer recovery actions will be carried out at the ingress OXCs of the affected lightpaths. A heuristic algorithm is implemented in the simulator for calculating the reroute path as follows:

First, an undirected graph $G_l$ is constructed based on the physical topology and wavelength availability status where an edge connecting vertices $< s,d >$ in $G_l$ denotes there are spare wavelength(s) in the link between corresponding physically adjacent node pair $< s,d >$.

Secondly, for rerouting an affected lightpath from node $s$ to node $d$, an alternative path with least hops from $s$ to $d$ can be found in $G_l$ using Dijkstra's algorithm, which implies a minimal number of spare wavelengths are used for rerouting this affected lightpath.

Note that wavelength conversion is assumed in every node in the network here, and when the wavelength converter is not available everywhere, a similar procedure has to be duplicated for each wavelength.

One lightpath consists of many LSPs. If the failed lightpath(s) are successfully rerouted in the optical layer, those LSPs carried by the affected lightpath(s) are also successfully rerouted, but they are not aware of the rerouting actions taken in optical layer. They only see the unchanged virtual topology, and the routes for those LSPs are also unchanged in the virtual topology.

But when the optical layer fails to reroute the affected lightpath(s) in the optical layer, the IP layer has to take charge of restoring the LSPs utilizing the affected lightpath(s). A lightpath has a fixed bandwidth and once the lightpath is established the wavelengths are occupied even if the fixed bandwidth is more than what the LSP triggering the lightpath setup requires. Thus, some spare capacity usually exists in the working lightpaths, and it is possible to reroute the LSPs using this spare capacity in the virtual topology. Furthermore, it also could happen that new lightpaths are established somewhere in the network for rerouting the LSPs, if it is necessary and free wavelengths are available. Thus, a problem similar to the virtual topology reconfiguration problem is involved here. Various heuristic algorithms have been proposed for this kind of virtual topology reconfiguration problem which is NP-complete [9]. They can be ported into our scheme with some modification. Here we do not need the "global" reconfiguration of virtual topology, that is, links in the existing virtual topology won't be removed and only new lightpaths need to be added to form the new virtual topology. Likewise, a heuristic algorithm is implemented in the simulation in the following steps:

Step 1: Construct a directed graph $G_v$, representing the current virtual topology. Each edge in the graph represents the existing lightpath that has enough spare bandwidth for the rerouted LSP, and they are tagged with 'exist'.

Step 2: Then add an edge in each direction between the vertices where there are spare wavelengths in the link connecting the corresponding nodes in the physical topology, and tag those edges with 'new'.

Step 3: So now the problem of minimizing used wavelengths is equivalent to the problem of finding a path with least 'new' edges, i.e. the shortest path in the $G_v$. The Dijkstra algorithm is used to find a shortest path on unweighted graph.

Step 4: For the path found in step 3, if the consecutive edges are the 'new' edges, combine them to be one 'new' edge. The resulting path is the route for rerouted LSP. Note if the node is without wavelength conversion, only 'new' edges with same wavelength can be concatenated.

The finer granularity of the LSP leads to better restoration ability, since each LSP is restored individually in the IP layer rather than all LSPs carried by the failed lightpath being restored together in the optical layer.

## IV. SIMULATION RESULTS AND DISCUSSION

### *A. Simulation Details*

For evaluation of the proposed multi-layer recovery strategy and inter-working mechanisms, a simulation program was developed based on OMNeT++ [10]. The results presented in this paper are based on the topology (see Figure 1) extracted from NSFNET, containing 14 nodes and 21 links.

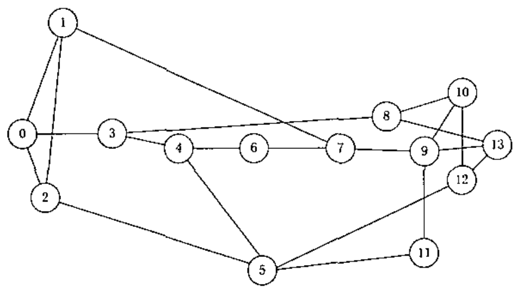


Figure 1: Network under study: topology of NSFNET.

Each node in the topology consists of an OXC and an attached LSR. They are connected with a single bidirectional fiber carrying 10 wavelengths and each wavelength has an OC-12 capacity (i.e. 622MBps). Wavelength converters are deployed at all network nodes. A single link failure scenario is assumed, which is the most probable type of failure in the networks.

We assume that a network design has planned an optimal bandwidth allocation and traffic loading on the network. Data traffic is flow-based and one LSP will be established for one traffic flow (i.e. no traffic aggregation at the MPLS level). Packets are generated according to a Poisson process. Recovery token is usually used as the mechanism to trigger the MPLS layer recovery.

### *B. Comparison of Recovery Schemes*

The performance of the two-layer restoration with recovery token inter-working is now compared with a single IP/MPLS layer restoration approach in Figure 2. The graphs show the average recovery ratio of affected traffic volume.

The most noticeable characteristic of the graphs is the two-step curve in case of the two-layer recovery. The optical layer rerouting is rather fast. With the given network and parameters, the optical recovery takes up to 40 ms and reaches an approximate mean recovery ratio of about 65% . Then the affected LSPs that cannot be rerouted in the optical layer will be rerouted in the IP/MPLS layer, triggered by the explicit recovery token without any delay. The MPLS rerouting finished in less than 350 ms. Totally 91% affected traffic is recovered at the end of the MPLS restoration interval. The single IP/MPLS layer restoration has a generally smooth curve, which means the recovery speed is slower in comparison to the first case. Around 93% of affected traffic is recovered after 800 ms. This is because a much higher number of LSPs have to be individually rerouted in the IP/MPLS layer. Thus, the two-layer restoration generally has a better recovery performance, since a majority of failed LSPs are recovered with a coarse granularity at high speed, which leads to less traffic loss and high throughput.

Another interesting feature is that the maximum restoration ratio is almost the same for both approaches. The main reason here is that the restoration (rerouting) scheme is used for both layers. On the other hand we can expect that if the protection scheme is deployed in the optical layer, a significant decrease in mean recovery ratio will be noticed due to the dedicated backup lightpath of MPλS protection.

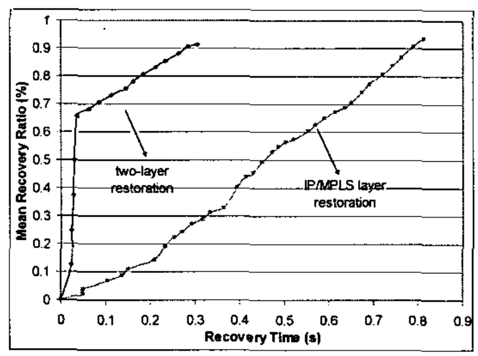


Figure 2: Performance comparison for different recovery strategies.

### *C. Hand-off timer vs. Recovery token*

The hold-off timer mechanism aims to simplify the implementation in the real network. The IP/MPLS layer recovery should be activated after the elapse of the hold-off time, if the optical layer recovery fails.

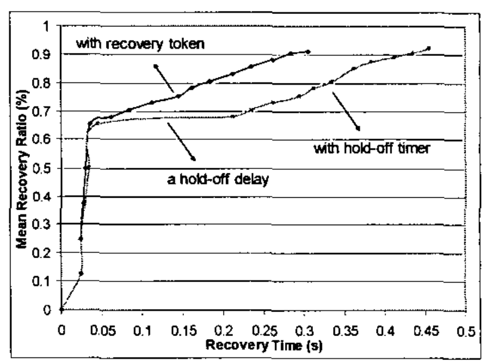


Figure 3 Comparison of recovery token and hold-off timer inter-working strategies.

In Figure 3 the performance of the recovery token strategy is compared to a hold-off timer inter-working strategy. As can be seen from the graphs, the recovery in the IP/MPLS layer using the hold-off timer starts indeed about 150 ms later than the recovery using a recovery token. This hold-off delay worsens the recovery performance in situations when the optical layer recovery fails. The network has to suffer more packet loss and lower throughput.

### *D. Influence of Wavelength Convertibility*

In the previous results, we assumed that the network is fully wavelength convertible. However, this is untrue in current optical networks, since wavelength converters are rather expensive.

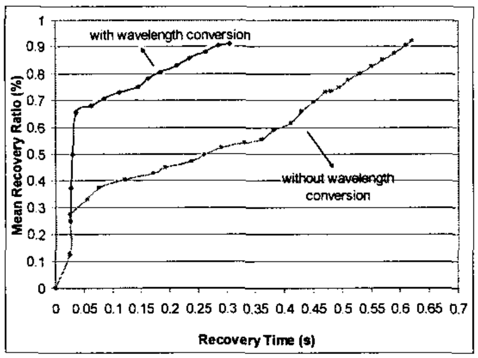


Figure 4: Performance comparison with/without wavelength conversion.

Figure 4 shows recovery performance of the proposed two-layer restoration scheme degrades significantly in a non-wavelength convertible network. With the same amount of spare capacity in both layers, optical layer rerouting is only able to recover up to 27.5% of affected traffic in around 25ms, while IP/MPLS layer can reach a maximum recovery ratio of about 92% in 650ms. We can see that the wavelength continuity constraint has a major effect on the optical layer rerouting. Without any wavelength conversion, a (backup) lightpath has to be set up between two nodes on the same wavelength. This greatly reduces utilization of wavelengths. While for MPLS rerouting, since the intermediate LSRs perform the O-E-O conversion, the wavelength continuity constraint has only a minor influence.

## V. CONCLUSIONS AND FUTURE WORKS

In this paper, an escalation recovery scheme was proposed for IP/MPLS directly over MPλS-enabled WDM based multi-layer networks. Recovery starts from the optical layer and the IP/MPLS layer is activated if the optical layer cannot restore all affected traffic. Both the recovery mechanisms at each layer and inter-working strategies were studied in the paper. The outcome of the current work showed that the proposed two-layer recovery scheme was superior to the traditional single layer recovery scheme.

The cases of a network with and without wavelength conversion were studied in this paper. Wavelength conversion was found that it had a major effect on our two-layer recovery scheme, especially for optical layer restoration. Studies about the network with partial wavelength conversion and the wavelength converters allocation problem will be included in the future works.

In the current study, only the path based rerouting (restoration) was used in both the IP and optical layers. Since protection is essentially different from restoration, there is interest in investigating the performance of the proposed two-layer recovery scheme with protection deployed at each layer or even combining protection and restoration at either layer.

Recently, the emerging Generalized Multi-protocol Label Switching (GMPLS) opens an opportunity to have a common control plane to operate across dissimilar network types. It would be interesting to study survivability in multi-layer transport networks equipped with GMPLS. This also will be left for further study.

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