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Hybrid Protection and Restoration Mechanism for High Speed Networks

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Abstract

This paper highlights network survivable schemes in order to guarantee both protection and restoration in high speed networks. In this paper, a hybrid protection and restoration mechanism has been proposed whose objective is allocating the bandwidth in a way that minimizes the total amount of bandwidth used for working and protection paths. In the proposed mechanism, path-based protection has been considered because it yields lower overhead and is also suitable for global optimization where, in case of a single link failure, all the flows utilizing the failed link are re-routed to a pre-computed set of paths. The simulation results demonstrate that proposed mechanism is much more efficient as it provides better quality of services (QoS) in terms of network resource utilization, blocking probability etc. as compared to conventional protection and restoration schemes. The proposed mechanism seems to quantify not only the capacity savings but also offers an attractive combination of features, with both ring like speed and mesh-like efficiency.

Keywords: *protection and restoration, network optimization, survivability, blocking probability*

1. Introduction

All-optical networks have been considered as the most reliable and cost-effective solution to obtain high transmission rates for long-haul distances with a low relative cost [1]. In these networks, the signal remains in the optical domain between the edge nodes without optical-electrical-optical conversion. One of the major challenges in all-optical networks is to ensure the quality of transmission (QoT) of the signal from the source to the destination node. Since an optical network carries a huge amount of data, a failure, such as a human error, an equipment failure or a natural disaster can imply in interruptions of some telecommunications services, leading to a technical or economic disorder [2]. In order to avoid this, optical networks have to be resilient to failures. An approach to increase the reliability of a communication path is to provision a disjoint backup path. In case the primary path fails, the traffic is routed through a backup path, if available. Network restoration has been studied in a variety of contexts, such as lightpaths in Wavelength Division Multiplexing (WDM) Optical Networks, Virtual Paths (VPs) in Asynchronous Transfer Mode (ATM) networks and most recently Label Switched Paths (LSPs) in Multiprotocol Label Switching (MPLS) networks and application layer paths in application overlay networks [2]. Research has focused on three main issues: robustness, efficiency and fast restoration. Robustness is a measure of the probability that primary paths cannot be restored. Efficiency is a measure of the capability of accommodating traffic. Fast restoration is a measure of the time taken to detect primary path

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failures and switch the route to backup paths. Although all-optical networks present lower cost when compared to opaque networks, the physical layer impairments have higher influence on the Quality of Transmission (QoT) of the lightpaths in all-optical networks. As a consequence, it is more difficult to find an appropriate route and assign a wavelength to attend to a call request. In general, a failure in a network element (link or node) can cause the interruption of several lightpaths, thereby leading to large data and revenue losses. Since a common requirement for commercial systems is full availability [3], all-optical networks must be fault tolerant in order to avoid service interruption. The only practical alternative to ensure this availability is to provide mechanisms to guarantee the continuity of services in the case of faults. Protection and Restoration are the two main survival schemes for optical networks [3]. Although both methods are used to ensure that the traffic is switched to a backup path in case of a failure, there is a subtle difference between them, which is related to when the backup resources are provisioned. Protection refers to the situation where the backup path is provisioned when the working path is set up. Everything is calculated before the failure occurs: the route, which resources to use and the switches are configured. This means that when a failure occurs, the backup path is ready for the traffic, ensuring fast and guaranteed traffic recovery. The main drawback of protection is its static nature due to the fact that recovery paths are pre-planned. Therefore, protection can only recover from failures that were anticipated (*e.g.*, a single span failure); if something unforeseen happens the traffic cannot be recovered. In restoration schemes, backup resources are searched and identified after the event of failure. Though restoration schemes cannot guarantee full recovery, they lower the network cost by increasing the capacity utilizations.

In this paper, a hybrid protection and restoration mechanism has been proposed whose objective is to route the flows and to allocate the bandwidth in a way that minimizes the total amount of bandwidth used for working and protection paths. The simulation results demonstrate that proposed scheme is much more efficient as it provides better quality of services (QoS) in terms of network resource utilization, blocking probability etc. as compared to conventional network survivable schemes.

The remainder of the paper is organized as follows. Section 2 reviews the various high speed network survivability issues and related work. The operation of the proposed hybrid mechanism is to provide network survivability, yielding lower overhead as well as capacity savings is discussed in Section 3. Section 4 analyzes the network performance and discusses the results extracted from simulations. Finally, Section 5 summarizes the main conclusion of the paper along with the future work.

2. Related Work

The survivability of networks is a very important issue and in recent years, there has been intensive research interest in the area of survivable network design. There are different types of network failure, but only two types among them are most common and most serious: link failure and node failure. Link failure means the fibers between the nodes in the physical layer are damaged, causing all the lightpaths between the nodes totally disconnected or unusable. Node failure means a workstation or a concentrator in the physical layer is damaged or unable to work due to power failure or for some other reason. The most common type of failure in WDM networks is the link failure [4]. Network survivability is generally supported by protection or restoration schemes [5]. In protection schemes, backup solutions are pre-planned and pre-established to ensure full recovery and short reconnection delay (defined as the delay from the moment the failure happens to the moment the transmission is resumed).In restoration schemes, backup resources are searched and identified after the event of failure.

The protection and restoration may be link-based or path-based [5]. In link-based schemes, upon a link failure, the affected connections are rerouted around the failed link. In path-based schemes, each affected connection is re-allocated to a backup route. Usually, path-based schemes achieve higher capacity efficiency with easier implementations, while link-based schemes achieve shorter recovery time.

Restoration describes the situation where a spare capacity pool is available in the network instead of pre-assigned backup capacity. In contrast to protection, a connection does not reserve spare capacity when the primary path is provisioned. Only when a failure occurs, a suitable backup path is identified and the necessary resources are reserved. Hence, a restoration scheme allows for more flexibility than a protection scheme when dealing with unexpected failures, because there is often more than one possible restoration path. But since the search for a restoration path only starts when a failure occurs, the recovery time is longer for restoration than for protection. Restoration is also called as dynamic protection where both path computation and connection setup are carried out after a failure occurs. Restoration is applied in mesh networks, where the high density allows for several recovery path alternatives. Furthermore, restoration can be applied in case protection cannot resolve a given failure situation, *e.g.*, a dual failure affecting both the working and backup path of a protected connection [6].

The ring protection scheme has been designed for synchronous digital hierarchy (SDH) networks but can be extended to WDM networks as well. Ring protection schemes ensure fast and simple switching, but they are not capacity efficient [6]. In span protection, the connection recovery is carried out between the two failure adjacent nodes. This means that the failure is dealt with locally, without involving the end nodes of a connection. The advantage of span protection is a short notification time, since the recovery is initiated by the same node that detects the failure. The drawback of span protection is a longer backup path and a large capacity requirement on the failure adjacent spans (*i.e.*, the spans connected to the failure adjacent nodes). In path protection, each connection is recovered between its end-nodes. In case of a failure, the end nodes of each individual connection must be notified of the fault, causing a delay before the traffic is switched to the backup path. The advantage of path protection is its freedom in route choice since there is no requirement of resuming the pre-failure path.

In [7], a new protection method with the aim of combining the advantages of ring and mesh protection is described. The method is called p-cycles and promises to achieve ring-like speed with mesh-like efficiency. The main idea of a p-cycle is to pre-configure a ring (i.e., a cycle) in a mesh network, where protection traffic is routed after a failure. The advantage of a p-cycle compared to a normal ring is that a p-cycle not only protects traffic that is on the ring, but also on spans that partition the p-cycle. These spans are called straddling spans. Within the field of p-cycles, several studies for evaluating p-cycle efficiency and finding suitable p-cycles exist. The majority of studies within the field of network survivability are carried out under the assumption of a single span failure. Even though they are the most common fault [7], other types of faults, such as node failures affecting multiple spans, dual span failures, multiple failures (more than two spans, combination of node and span failures, *etc.*,) may occur as well. In [8-9], several studies have shown that the more failure scenarios a network is protected against, the higher the total capacity usage. The probability of multiple failures also increases with the size of the network. This is both in terms of the amount of equipment, each with a given failure probability and in terms of the geographical extent.

Ramamurthy and Mukherjee [10] demonstrated that multiple possible lightpaths between pairs of nodes can improve the blocking probability for a wavelength-routed optical network (WRON). They also demonstrated that it is important to find optimized alternative routes between pairs of nodes to exploit the connectivity of the network topology. Pavani and Waldman [11] proposed an algorithm based on the ant colony optimization to allow the search for alternative paths in order to minimize the number of blocked lightpaths. Huang *et al.*, [12] investigated the survivability of service paths based on the differential delay constraint and multipath provisioning together in backbone mesh networks. They compared their proposal with the k-shortest link-disjoint paths algorithm. Agraz *et al.*, [13] evaluated a centralised impairment-aware path restoration approach for transparent optical networks. The work focuses on the capability of the centralised scheme to detect failures and restore the affected connections while ensuring acceptable quality of transmission (QoT). Askarian *et al.*, [14] evaluated the performance of several link protection and link and path restoration algorithms in all-optical networks with realistic physical layer impairments and proposed a new cross-layer restoration method. Freitas *et al.*, [15] proposed a path restoration algorithm that establishes an alternative ligthpath that presents the maximum optical signal-to-noise ratio in the destination node.

Using above comprehensive related research work, it is concluded that restoration schemes are more efficient in utilizing the capacity of the network due to the multiplexing of the spare-capacity requirements and provide resilience against different kinds of failures, while dedicated-resource protection schemes have a faster restoration time and provide guarantees on the restoration ability [7].

3. Proposed Hybrid Protection and Restoration Mechanism

The following is the brief description and working of the proposed hybrid protection and restoration mechanism.

1. A physical optical fiber network represented by a directed graph $G_p = (V_p, E_p)$ with $|V_p| = N$ (the number of end nodes) and $|E_p| = m$ (the number of physical links).

2. The WDM network model used in proposed mechanism is a mesh topology consisting of a number of end nodes (each end node is associated with a router node) and a number of physical links connecting two end nodes. Each link between end node 'i' and end node 'j' is bi-directional and consists of two unidirectional fibers. It is assumed that the capacity of each fiber (i.e. the number of WDM channels available on the fiber) and the capacity of a single WDM channel of each fiber (i.e. the maximum amount of traffic it can carry) is the same.

3. A traffic demand matrix $T = \{t_{sd}\}$, where t_{sd} is the total amount of traffic requests between a source node s and a destination node d.

4. Each fiber in the network can accommodate W channels (W = 64). Upon a link failure, the end nodes of each interrupted connection are informed.

5. The link-state information along the backup route is collected. Based on the collected link-state information, a certain node, usually the source or the destination node of the interrupted connection, decides on the wavelength assignment.

6. Each restoration operation searches through all the wavelengths in a pre-defined sequence and selects the *first* available one among them. If no available wavelength exists along the backup route or if the selected wavelength later turns out to be reserved by another reservation request arrived earlier, the restoration request will be blocked.

7. Link-disjoint paths are created by successively applying Dijkstra's algorithm to each node pair. After finding a shortest path for a particular source-destination pair, the links used by this shortest path are deleted from the physical topology. This process is repeated until an optimal set of shortest paths are found. This provides greater flexibility in routing and wavelength assignment for a particular source-destination pair and usually keeps the path lengths small.

8. It is assumed that each restoration request is initialized by the source node of the interrupted connection. A wavelength at an early position in one searching sequence should be at a late position in the other sequences, so that the chance that the two operations select the same wavelength is lowered.

9. For each source-destination nodes pair, generated by a uniform distribution, the proposed hybrid survivable technique aims to establish a primary lightpath which presents an acceptable QoT. For each link 'L' belonging to the topology 'T', composed by Nodes and Links, calls that pass through it are identified and then a failure rate is simulated. If a primary lightpath is found, the proposed technique finds a backup lightpath by searching a route composed by the links L_0------------L_n. After that, it verifies if the *w* wavelength is available from the L_0 link until the L_n link and if the sharing limit in each link is below the maximum value. The function QoT (n_s ,n_d, w) evaluates the quality of transmission of the search-route in the w wavelength, from the n_s source node until the n_d destination node. If QoT (n_s ,n_d, w) is acceptable, then the *w* wavelength is assigned to the search- route and the number of times that the *w* wavelength is used in each link is incremented.

10. The following is the brief working of pseudo-code of proposed dynamic hybrid survivable scheme.

//Pseudo-code of Proposed Hybrid Mechanism for High Speed Networks//

```
for each L ε T (Nodes, Links) do
    Identify the calls ε L;
    for every link of the network do
            Select the calls which pass by the link;
            Form a copy of the network in the stable state;
      for w =0 to W do
          Search for a backup route= (Lo.......Ln);
          if (QoT (ns ,nd, w) = true) then
           Assign as backup lightpath the search route and the w wavelength;
          end if
      end for
      for every call that passes through link do
            Make free the occupied lightpaths which pass by the link;
       end for
       Simulate link failure;
       for every call that passes through link do
            Search for an alternative route considering higher optical signal-to-noise ratio;
            Determine wavelength and path availability;
            Find physical layer impairments; Evaluate quantity of recovered calls;
       end for
            Determine link failure rate;
      for each L ε T (Nodes, Links,  minimum path (Pathmin)) do
          Find the shortest path (Psp) from ns  to nd;
        if cost of Psp< Pathmin then
           p = Psp;
        end
      end for
   end for
end for
```

11. The proposed mechanism for provisioning alternate capacity ensures that no single failure in the network will result in unavailability for any demand. The computation of restoration capacity on each link comprises of (i) determine the demands for which this link is part of the alternate route. (ii) for the demands computed in (i) find the union of links and nodes on their primary routes. This set constitutes all possible failures that would result in alternate capacity being required on the current link. (iii) for each link in the set in (ii) find the multiplicity i.e. the number of demands that use that link on their primary routes and their sizes. (iv) alternate capacity required on the current link is equal to maximum multiplicity over all the links from the set identified in (ii).If demands are of different sizes, then it is the sum of those demands, not just the maximum multiplicity. The proposed hybrid mechanism seems to quantify not only the capacity savings and, in some cases, the service quality improvements but also offers an attractive combination of features, with both ring like speed and mesh-like efficiency.

4. Performance Evaluation

The topology used for simulation is 4×4 mesh-torus network, where the length of each link is 100 km. The results for network traffic simulations have been obtained using the software Network Simulator [16] and for analytic results, data processing and plotting are carried out using standard commercial software. It is assumed that each link is composed of two directional fibers of opposite directions with 64 wavelength channels (W) per fiber. The backup route is the shortest hop-length path that is link-disjoint to the route of the original lightpath. It is assumed that the original lightpath establishment is on the route with the minimum number of hops between source-destination nodes, *i.e.*, the route with the shortest hop length. The processing delay for handling each restoration request on each node is assumed to be equal to 10 microseconds. Link transmission rate is 2.5Gb/s. Each node maintains global network state information for routing and this information is periodically updated. The link failure is generated randomly with a uniform distribution on each link. For each given traffic load, the connection requests are assumed to be arriving from a Poisson process with an exponentially-distributed duration. The average duration of each connection is one hour. A large number of connection requests have been simulated until the network has reached a stable status (*i.e.*, the blocking probability converges). The performance of the proposed scheme is evaluated by the restoration blocking probability. Optical packets are fixed at 500bytes, which is assumed to be a representative average in IP-packet networks (variable size packets and bursts will be object of future implementation). The destination of each connection request is uniformly distributed. The routing time is 1ms. The unit propagation delay on each link is 0.5ms. The wavelength reservation time is 0.01ms. The mean holding time of each connection is 500ms. The other network parameters are: amplifier output saturation power of 26dBm, input optical signal-to-noise ratio of 40dB, optical signal-to-noise ratio for QoT criterion of 23dB, optical filter bandwidth of 100GHz, channel spacing of 100GHz, zero dispersion wavelength in 1557nm, fiber loss coefficient of 0.2 dB/km, multiplexer loss of 2dB, de-multiplexer loss of 2dB, optical switch loss of 2dB, noise figure of 5dB and transmitter laser line-width of 0.05nm. For protection and restoration analysis, single link failure is considered only, because the probability of double simultaneous failures is at least two orders of magnitude smaller and does not contribute to the present analysis.

From the simulation results (as shown in Figure 1), it is observed that the proposed hybrid mechanism almost always outperforms the existing ones; and the improvements tend to become more significant under lower traffic loads with more redundant network resources for wavelength-assignment selections. This is because in the proposed hybrid scheme, the restoration requests are sorted in an increasing order of the hop lengths of their backup routes. As a result, almost all the restoration requests with short backup routes are successfully accepted (at the cost of those restorations with long backup routes). Under heavy traffic loads, all survivable schemes perform nearly the same, dominated by the effects of exhausted network capacities.

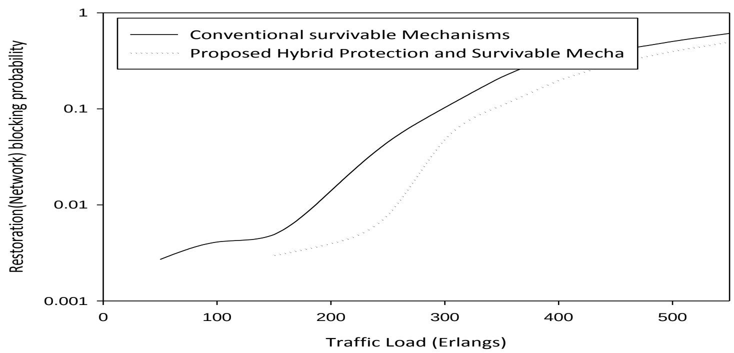

Figure 1. Restoration (Network) Blocking Probability Vs Traffic Load

The comparative results for the throughput in the ring and mesh networks, with and without failure are shown in Figure 2. Using proposed hybrid mechanism, it is observed that the mesh topologies moderately reduce their performance, with respective throughput reduction averages of 11, 6.5, and 4%. For the corresponding ring topologies, the observed throughput values reduce as much as 26, 25 and 24%, respectively, demonstrating the fragility of ring as compared to mesh. Moreover, since all links are practically equivalent in ring, it is more difficult not only to decide where to protect (protection for the whole network is too costly), but also to locate failure and to provide restoration, considering that the modelled networks span for tens of kilometres. Using proposed scheme employing mesh topologies, these difficulties are minimized.

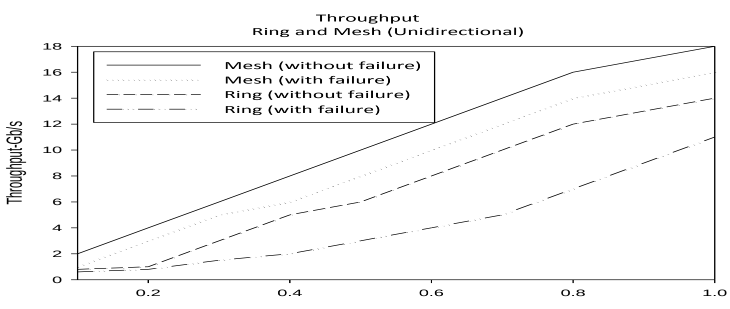

Figure 2. Network Throughput Vs Link Load

Finally, using above simulated obtained results, the proposed scheme seems to quantify not only the capacity savings but also offers an attractive combination of features, with both ring like speed and mesh-like efficiency in optical networks.

5. Conclusion and Future Scope

It is observed that sharing of backup wavelengths promotes an increase in the optical network survivability. Also, it is seen that existing protection and restoration schemes such as

1+1 demand architectures enjoy both fast restoration times and very high availability; they also run the highest cost. Also 1+1 dedicated protection networks are more expensive than their shared mesh counterparts by 15-45%. Simuation results obtained show that proposed hybrid survivable scheme employing shared mesh architectures provides not only availability characteristics competitive even with existing designs at a substantially lower cost but also balances the improvement in the survivability and the decrease in the computational complexity and time.

Further, it is expected that the present work contributes to better understanding of optical traffic dynamics in future optical packet switching (OPS) or optical burst switching (OBS) networks and to identify which network topology connections are more critical to be protected and rapidly restored.

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