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# Pre-Allocated Restoration Technique in a Distributed GMPLS-Based Mesh Optical Network

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**Abstract:** Providing survivability schemes under different failure scenarios is important for service providers of backbone networks in order to address the physical topology constraints and long-distance fibre installations associated with a higher risk of failure. One of the challenges in this domain is to reduce the amount of required spare capacity while providing the required quality of service (QoS). A candidate to meet this challenge, due to its flexibility in terms of resource utilisation and ability to cope various failure scenarios, is the pre-allocated restoration technique. Additionally, pre-allocated restoration techniques achieve simplicity in terms of implementation and operation; additional capacity specifically for survivability purposes is embedded in the network. In this paper, the pre-allocated restoration performance is investigated under single and dual-link failures considering a distributed GMPLS-based mesh optical network; a promising core structure for future networks. Two main issues are investigated; firstly, retrial methods that support the utilisation of spare capacity, and secondly, the differentiated survivability concept that supports quality of service with pre-allocated restoration.

**Key words:** Distributed Model, GMPLS, Optical Mesh Networks, Survivability, Pre-allocated Restoration, Dual-link Failures.

## INTRODUCTION

Over the last few years, the research and industrial communities have increased their efforts in the development of optical network technologies, both at the physical and management layers, in order to progress beyond point-to-point transmission systems and proceed to all-optical networks. Consequently, the Optical Transport Network (OTN) structure consisting of a data plane and control plane has been introduced. The OTN structure is independent of any client layer, providing support for a range of diverse services and client types. Generalised multi-protocol label switching (GMPLS) has been introduced by the Internet Engineering Task Force (IETF) to form an intelligent control plane for the OTN. Such intelligence drives from the techniques and protocols used by the GMPLS standard. This control plane is then able on-demand to establish and tear down lightpaths and to provide quality of service (QoS) and recovery capabilities [1-3].

Survivability has now become a key concern of network operators, particularly with the deployment of OTNs in core networks. There are many reasons for this. Firstly, OTNs support an enormous capacity, and therefore, a single failure may have an impact on a large amount of traffic. Secondly, introducing the next generation Internet, whereby the IP layer is built directly over the optical layer, eliminates the SONET layer which was traditionally responsible for providing survivability in optical networks. Therefore, the main challenges include; achieving SONET layer features with a minimum amount of spare capacity, dealing with different failure scenarios, and providing QoS [4-5].

Most recent studies attempt to achieve these challenges as far as possible by considering the multiple trade-offs between the various performance parameters of survivability. These trade-offs include spare capacity, restoration time, restorability, reliability, availability, scalability, and simplicity.

Based on the trade-off between the various aspects of survivability performance parameters and the management of these requirements, survivability can be broadly classified into protection, restoration and pre-allocated restoration techniques. The distinction

between these techniques is based on the timing of spare capacity allocation and the timing of backup route calculations. Thus, the term protection is used to describe schemes that are pre-planned for both spare capacity and backup routes, whereas restoration schemes plan both spare capacity and backup routes after failure occurrences. Pre-allocated restoration schemes use pre-planned spare capacity only. It is clear that protection schemes achieve the shortest restoration time and provide guaranteed recovery, while restoration is flexible in terms of resource utilization and coping with various failure scenarios [5-7].

The pre-allocated restoration technique, considered in this work, falls between the protection and restoration techniques. It is very simple in terms of implementation and operation. In this technique, additional capacity specifically for survivability purposes is embedded in the network. The amount of this capacity can be calculated by an off-line algorithm based on the required survivability performance or adjusted, on-line, based on network conditions. The restoration capacity is unseen by the routing algorithms under no-failure conditions. It is possible to manage using this capacity with low priority or pre-empted traffic under normal operation [8-10].

Moreover, the pre-allocated restoration technique is more flexible in terms of resource utilisation and coping with various failure scenarios. Survivable routing computation and resource allocation are involved only once the failure has been notified.

From the above discussion, it is clear that the pre-allocation restoration technique achieves the most efficient survivability performance in comparison to the protection and restoration techniques. Hence, with the pre-allocated restoration technique, several issues are worth investigating including spare capacity allocation and implementation. From the spare capacity perspective, it is important to consider the spare capacity allocation, optimization, reconfiguration, and utilization under failure and no-failure conditions. From the implementation perspective, it is essential to investigate the technique's efficiently in terms of coping with various failure scenarios and provide QoS and its scalability in terms of required routing information. Therefore, this paper considers the spare capacity allocation and technique implementation with the GMPLS-based optical mesh network. Other spare capacity issues will be addressed in the future work.

The paper is organized as follows; Section 2 presents the problem discussion. The model implementation and assumptions is considered in Section 3. Section 5 describes the model performance and simulation results. Finally this paper is concluded in Section 5.

## 1. Problem discussion

Providing survivability schemes under different

failure scenarios are becoming a critical concern for service providers of backbone networks. The most dominant scenario is a single-link failure. Recently, the dual-link failure scenario has become a real motivation for both designers of survivable networks and service providers [4-5]. The reasons are, first, the occurrence of dual-link failures is now highly probable in large-scale networks, as a result of the physical topology constraints and long-distance fibre link installations. The second motivation arises from the improvement of optical layer functionality, in which most functions are facilitated through a GMPLS-based distributed control plane rather than any centralized management unit. This improvement makes it possible, by adopting restoration mechanisms and differentiated survivability concepts, to provide survivable schemes that can significantly reduce the cost of dual-link failure recovery [11].

Even though protection techniques, due their ability to provide a guaranteed recovery connection, are the dominant survivability technique they are not scalable in terms of coping with different failure scenarios. For instance, providing a protection scheme for dual-link failure requires almost triple the amount of spare capacity compared to the protection schemes against single link-failure. In contrast, restoration techniques can scale well against various failure scenarios. However, connection recovery is not guaranteed in all circumstances. Therefore, it is essential to investigate alternative approaches that can efficiently stand against different failure scenarios while providing the required quality of service (QoS). This paper investigates the performance of applying the pre-allocated restoration technique in the distributed GMPLS-based mesh optical network under single and dual-link failures.

## 2. Related work

Most studies related to network survivability have considered protection and restoration techniques to provide survivability schemes against single-link failures[5]. Some recent studies have conducted work on both pre-allocated restoration and dual-link failures. From a pre-allocated restoration perspective, [8] compares the characteristics of shared backup path protection technique with the pre-allocated restoration proposal known as the 'protected work capacity envelope concept'. Algorithms for computing the link capacity partitions (restoration capacity and normal work capacity) is presented in [9-10]. From the dual-link failure perspective, three techniques are investigated, including, reconfiguration, two pre-planning backup paths, and re-routing [12-16]. Recently, in [17], a comparison between re-routing (with and without stub-release), dedicated path protection and shared path protection in terms of required capacity was presented.

In [7] the performance comparisons between path, subpath and link restoration were presented under single link-failures, using distributed GMPLS control signaling. This paper extends the work presented in

[7] by using retrials with the pre-allocation technique for both single and dual-link failures with QoS considerations.

## 3. Model implementation and assumption

This work uses the OMNeT++ (Objective Modular Network Testbed in C++) discrete-event simulation platform. OMNeT++ is an object-oriented modular test-bed simulator, whereby each module in the network is implemented as an object. Additionally, it supports hierarchically nested modules with flexible module parameters. Therefore, OMNET++ provides a suitable platform that supports modeling of distributed mesh topologies.

### 3.1. Model structure:

The network topology used in this work is the European network topology as shown in Figure 1. It consists of a set of OXCs, connected by a set of paired fibre links. Dedicated channel in each link comprise the control plane topology in which control messages are exchanged independently from the data plane topology. Internally, an OXC consists of two main parts: a control plane and a data plane. The control plane consists of three units: the signaling, the routing, and the recovery unit. The functionalities of the signaling and routing units are implemented using standard GMPLS protocols as described in the Internet drafts [18-20]. This work focuses on the implementation of the recovery unit functions in conjunction with other protocols. The data plane is essentially a hardware foundation. It is responsible for switching the incoming traffic to an appropriate output wavelength, according to the information presented in the wavelength routing table and wavelength conversion availability.

Each OXC has a controller model in charge of controlling and scheduling all required functions in the node. Moreover, it is responsible for delivering messages to remote nodes through dedicated control channels, using GMPLS standard protocol messages which could be generated locally by the signaling unit or passed over to other nodes.

OXC units require particular information in order to efficiently implement their functionality. Furthermore, the amount of information significantly impacts on model scalability. Three data tables were used in the OXC implementation.

o Wavelength routing table: contains the information that describes the status of wavelengths at each port.

o Lightpaths information table: maintains the information about all lightpaths generated from, or terminated on, the corresponding OXC. Specifically, the lightpath route information is maintained here. This information enables the control plane, to change or modify the lightpath route in order to improve network performance or to recover from failures.

o Network Physical topology table: contains the information about the entire network link connectivity. This information enables the routing unit to calculate the appropriate route for a new request.

The model considers three delay components; the propagation delay, the transmission delay and the nodal process delay. The propagation delay represents the delay for the first bit to travel from a source to a destination and is a function of the link propagation speed and the link length. Transmission delay represents the time needed to pump data onto a link, and it is calculated as a function of link capacity and message size. The nodal process delay describes the time between the node receiving a message through the input port and the time when the message is sent to the output port, including the time taken to examine a message, to calculate a new route, and wavelength switching.

### 3.2. Model assumption under failure conditions

Failures are generated randomly. The inter-arrival time and holding time of failures are generated based on an exponential distribution. Links selected for
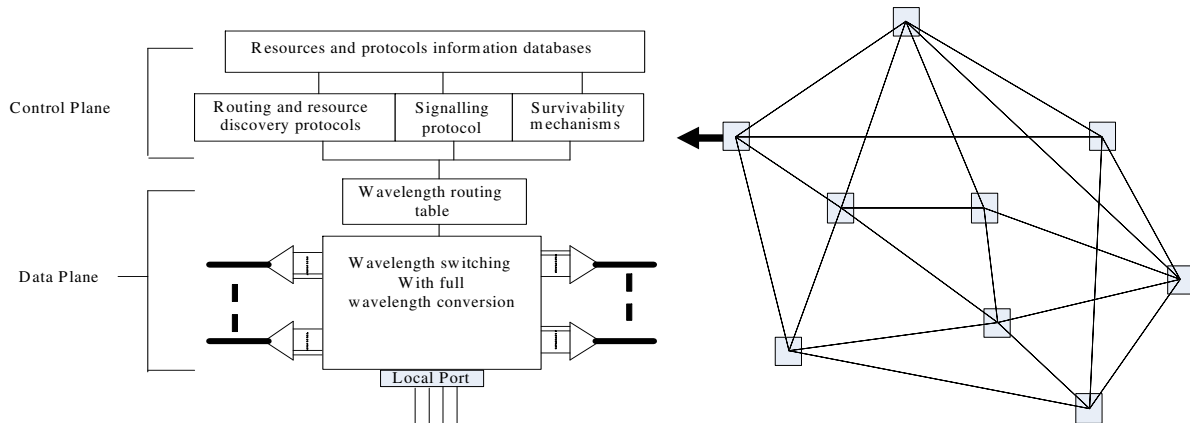


Fig. 1: Network topology and the OXC structure

failures are obtained using a uniform distribution. The dual link failure scenario considered in this work sees two random links fail simultaneously. The path-level pre-allocated restoration is applied with a fixed number of wavelengths reserved in each link. The recovery procedure starts at the two nodes adjacent to the broken link. These two nodes include the upstream node, closest to the lightpath source, and the downstream node closest to the lightpath destination. The downstream node for any failed connection sends a tear down message towards its destination while the upstream node sends a notify message towards its source. Once the source receives the notify message, it attempts to calculate a new recovery route.

The spare capacity is allocated within all links whereby the link wavelengths are partitioned into two parts; working wavelength and restoration wavelengths. From the routing calculation point of view, each link is advertised in terms of four parameters; maximum number of wavelengths (W), maximum restoration wavlengths (R), current working wavelengths (w), and current restoration wavelengths (r). The first two parameters are more or less preset while the last two parameters must be updated by the GMPLS routing protocol such as Open Short Path First (OSPF). Based on these parameters, the link weight (Lw) which is equal (1/available wavelengths) can be calculated using formulas (1) to (3):

$$L_w = \begin{cases} \dfrac{1}{W - (w + r)} & if \quad r >= R \quad (1) \\[2em] \dfrac{1}{W - w - R} & if \quad r < R \quad (2) \end{cases}$$

a) For a normal LSP request

$$L_w = \frac{1}{W - (w + r)} \qquad (3)$$

b) For the restoration LSP requests

One of the critical problems in path-level pre-allocated restoration is contention between messages, which arise when the multiple provisioning processes begin simultaneously. The suggested solution is to apply a retrial method. Therefore, when the connection recovery process failed, the restoration process can be repeated. The retrial method performance is affected by the number of retrials and the time delay between the retrial events.

The second critical issue with path-level pre-allocated restoration is to provide QoR. The solution is to apply a suggested recovery class prioritisation method. Using this method, a discrete time interval between classes is preset. During each time-interval, one class invokes the recovery method. It is assumed that the method operates independently at each node. It is possible to apply the retrial method within any time-interval to enhance performance in the corresponding class. The length of the discrete interval

between classes directly affects the restoration time for each class. This is a parameter that is considered in the experimental work.

### 3.3. Model assumption under no-failure conditions

Lightpath connections are requested and terminated randomly with requests arriving based on a Poisson process. The lightpath parameters include the source, the destination, and the service class, selected randomly based on a uniform distribution. The routing units determine the shortest path based on the number of free wavelengths in each link. The first fit wavelength assignment strategy was considered. Full wavelength conversion is assumed. Lightpath provisioning employs the destination-initiated reservation (DIR) method using the GMPLS signalling protocol. Based on the DIR method, a connection request is forwarded from the source to the destination and collects the resource information on its way. The destination then selects the appropriate label (wavelength) and sends a reservation request to the source. The source and intermediate nodes attempt to find and reserve the required resource. The connection request will be blocked if there are no available resources along its route. It is assumed that no repeat behaviour is considered.

## 4. Performance results

This section presents results for a number of simulation-based experiments. The performance metrics of interest are the restoration rate and restoration time. The former gives the ratio of the number of restored connections over the number of failed connections in the network. The latter is defined as the ratio of the total restoration time of restored connections over the number of restored connections. The offered load presents the traffic load expressed in Erlangs, which is defined as the product of mean arrival rate, and the mean connection holding time. For simplicity and inline with other previous work[21], it is assumed that all links are equal in terms of length (1000 km) and number of wavelength (12 wavelength), the message length is fixed at 256 bytes, and the nodal process delay is 20ms.

The mean failure inter-arrival time is 5 time units (time unit equal 50s) and the mean repair time is one time unit. These particular values were adopted primarily as a result of experimental expediency in order to set limits for the experimental work. It is recognised that the numerical values are lower or different than those experienced in practical networks; the results attained represent reasonable limits under the consideration to provide multiple failure events.

Figures 2a and 2b present the pre-allocated restoration rate and restoration time for single- and dual-link failures with and without retrial methods, with different pre-reserved wavelengths. All values are recorded at the same network load (140 Erlangs). The experimental results show that both the restoration rate and the restoration time are improved when the numbers of pre-reserved wavelengths increase.
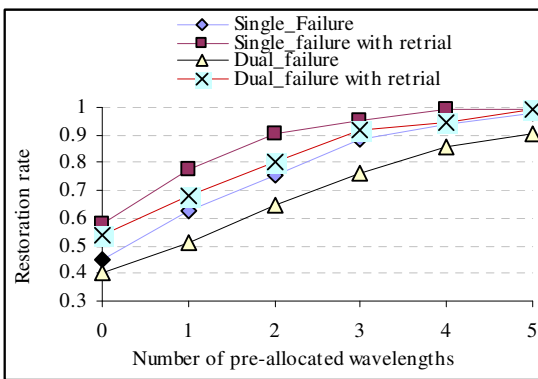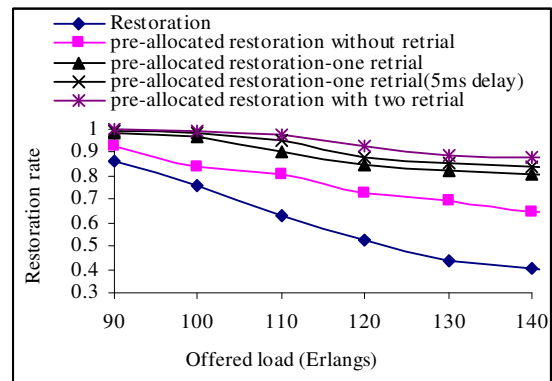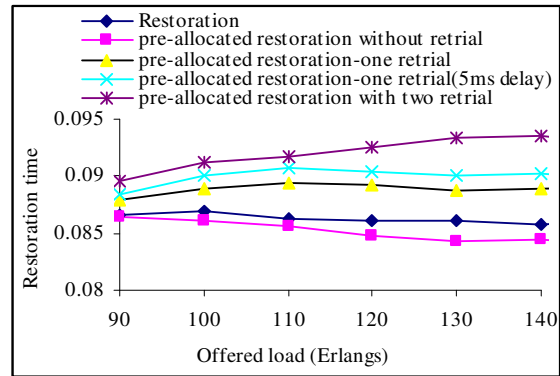
(a)
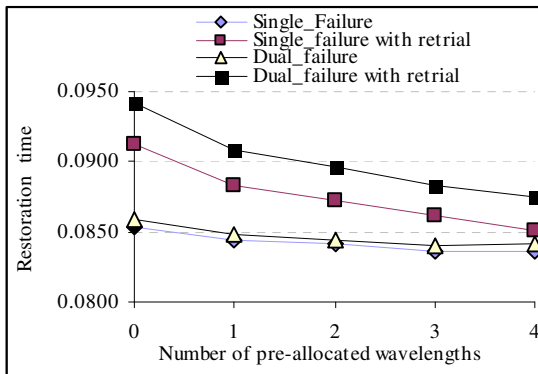


(b)

Fig. 2: Performance comparison for pre-allocated restoration performance under single- and dual-link failure.



(a)



(b)

Figure2: Performance comparison for multilayer restoration and the two spare-capacity allocation methods

Additionally, the figures show that there is a trade-off between the pre-allocated restoration performance parameters when the retrial method is applied. While the restoration rate is improved significantly under the retrial method (one retrial with 1ms delay), the restoration time is increased significantly. This experiment demonstrated clearly the effect of contention problems in the GMPLS-based distributed network model, in which the restoration rate of dual-link failures with retrials exceeds that of the restoration rate for single-link failures without retrial.

In Figures 3a and 3b, a performance comparison between the restoration technique and pre-allocated technique with various retrial parameters are presented. All pre-allocated restoration performance values are recorded at the same number of pre-reserved wavelengths (2 wavelengths). It is notable that a dual-link failure increases the number of lightpaths failed simultaneously, and therefore, it is possible to adjust the retrial parameters to achieve the required performance. Two parameters have investigated the number of retrials and the retrial delay. The experimental results again show that there is a trade-off between the dual-link failure restoration performance parameter when the number of retrials increase and a retrial delay is used. Therefore, appropriate values for these two parameters depend on

the required level of performance.

The differentiated survivability concept is investigated in order to provide QoR in the pre-allocated restoration technique. Figure 4a and 4b, illustrate the restoration rate and restoration time for the preset connection classes. The recovery class prioritisation method has a preset time-interval (5 ms) between classes. The experimental results show that the performance of class 1 is significantly improved using the recovery class prioritisation method in terms of both the restoration rate and the restoration time, by comparison with class 2. Additionally, class 2 achieves better performance than class

## 5. Conclusion

In this paper, the performance of the pre-allocated restoration technique was investigated under single and dual link failure scenarios. The work presented in this paper is based on a simulation model built using OMNET++ which considered a distributed GMPLS-based mesh optical network model. Several pre-allocated restoration performance aspects were investigated in this paper including, the retrial method and its associated parameters, the recovery class prioritisation method to provide quality of recovery with the pre-allocated restoration technique.
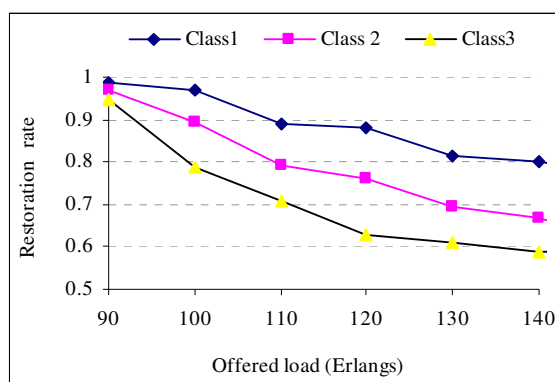
(a)
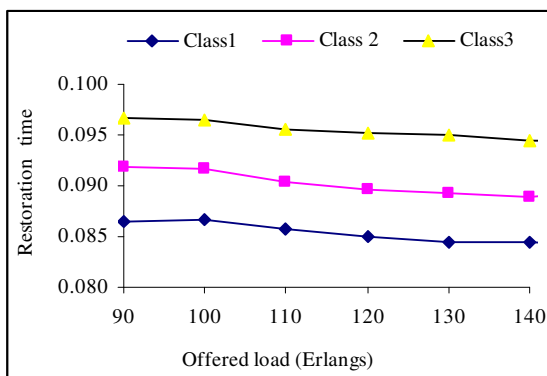


(b)

Fig. 4: Performance comparison for different classes under the pre-allocated restoration technique.

The experimental results show that the pre-allocated restoration technique is affected by several parameters. Firstly, the amount of pre-reserved restoration capacity which results in an increase of the overall network performance along with an increase in reserved capacity. Secondly, the retrial method and its associated parameters (number of retrial and retrial delay) clearly show that there is a trade-off between the restoration rate and restoration time. Additionally, the results proved that using the pre-allocated restoration with the retrial method is very efficient for dual-link failure scenarios.

Moreover, this paper investigated quality of recovery under the pre-allocated restoration technique. It suggested a recovery class prioritisation method that uses a discrete range of time-intervals between classes. At each interval, one class is trailed to recover from a failure. The results show that this method is an efficient method to provide quality of recovery (QoR) with pre-allocated restoration in terms of scalability and simplicity; it operates independently at each node and its simple implementation within the GMPLS protocols.

The pre-allocated spare capacity optimization, reconfiguration, and utilization under failure and no-failure conditions will be addressed in the future work.

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