Optical Networks: Design and Modelling

OPTICAL NETWORKS: Design and Modelling

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IFIP - The International Federation for Information Processing

IFIP was founded in 1960 under the auspices of UNESCO, following the First World Computer Congress held in Paris the previous year. An umbrella organization for societies working in information processing, IFIP's aim is two-fold: to support information processing within its member countries and to encourage technology transfer to developing nations. As its mission statement clearly states,

IFIP's mission is to be the leading, truly international, apolitical organization which encourages and assists in the development, exploitation and application of information technology for the benefit of all people.

IFIP is a non-profitmaking organization, run almost solely by 2500 volunteers. It operates through a number of technical committees, which organize events and publications. IFIP's events range from an international congress to local seminars, but the most important are:

- The IFIP World Computer Congress, held every second year;
- open conferences;
- working conferences.

The flagship event is the IFIP World Computer Congress, at which both invited and contributed papers are presented. Contributed papers are rigorously refereed and the rejection rate is high.

As with the Congress, participation in the open conferences is open to all and papers may be invited or submitted. Again, submitted papers are stringently refereed.

The working conferences are structured differently. They are usually run by a working group and attendance is small and by invitation only. Their purpose is to create an atmosphere conducive to innovation and development. Refereeing is less rigorous and papers are subjected to extensive group discussion.

Publications arising from IFIP events vary. The papers presented at the IFIP World Computer Congress and at open conferences are published as conference proceedings, while the results of the working conferences are often published as collections of selected and edited papers.

Any national society whose primary activity is in information may apply to become a full member of IFIP, although full membership is restricted to one society per country. Full members are entitled to vote at the annual General Assembly, National societies preferring a less committed involvement may apply for associate or corresponding membership. Associate members enjoy the same benefits as full members, but without voting rights. Corresponding members are not represented in IFIP bodies. Affiliated membership is open to non-national societies, and individual and honorary membership schemes are also offered.

PREFACE

Recently the term *optical networking* is widely used by Telecom people, to express the capabilities of routing and switching channels directly in the optical domain without opto/electronic conversion. In fact, all-optical networks are those in which the path between the using nodes at the ends remains entirely optical from end to end. Such paths are usually named *lightpaths*. Optoelectronic technology, which enables the realization of optical networks, are approaching functional and economic feasibility.

As a consequence more and more people worldwide are investigating them as possible base upon which networks of the future can be built, both within the wide-area backbone and for the metropolitan and local area distribution facilities.

The motivations for optical networks success basically stay the possibility of satisfying the growing demand for i) bandwidth per user, ii) protocol transparency, iii) higher path reliability, and iv) simplified operation and management. In all these matters, there is evidence that classical time division multiplexing (TDM) approaches realized in electronic circuitry of ever-increasing speed, variety and complexity, are slowly beginning to prove insufficient; that means either that older technology cannot do the required job as cheaply or that it cannot do it at all and the optical approach can.

Among the different approaches toward realizing high-capacity, protocol transparent optical networks, wavelength division multiplexing (WDM) offers the best promise in the near term. In fact, while enabling meaningful capacity enhancements, WDM technique provides the means for novel networks in which the paths routing is directly accomplished in the wavelengths domain. Indeed, WDM networks offer potential advantages, including higher aggregate bandwidth per fiber, new flexibility for automated network management and control, noise immunity, transparency to different data formats and protocols, low bit-error rates, and better network configurability and survivability: all leading to more cost effective networks.

The papers contained in the present book address several hot topics relating to optical network design and modelling.

Optical networking issues as the routing algorithms and wavelength conversion and assignment are treated in the first two parts, respectively. Examples of the application of optical technology for the realization of local and access networks are reported in the papers of the III part. The key topic of transmission of optical signal within an optical transport network is treated in four papers of the IV and V part. New paradigms relating to traffic models are introduced and discussed in part VI. Other advanced topics in optical network, such as the relation between ATM and optical technologies, are reported in the last part.

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CONTENTS

PART ONE

Routing algorithms for optical networks

Restoration methods for multi-service optical networks

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Abstract

In this paper, we apply different restoration strategies for different optical network services in multi-service optical WDM networks according to the user requirements and availability of network resources. For that purpose optical network services provided to the user networks like SDH or ATM are classified according to the quality degree and restorability required. In particular, the restoration means dynamical re-establishing of circuits, which are generally dynamically or statically assigned. The numerical results for networks with a random restorable topology and four classes of service quality degree as well as for service-specific restoration methods are presented and studied on their applicability.

Keywords

Optical network service, WDM networks, QoS-routing, restorability, blocking probability

INTRODUCTION

One of the key parameters of interest for client networks like SDH (Synchronous Digital Hierarchy) or ATM (Asynchronous Transfer Mode) is the service restorability in optical networks. This issue is even more important in case of optical wavelength division multiplexing (WDM) networks where a single fibre is carrying enormous amount of data and a fibre break has an massive impact on carried traffic. The restoration, as discussed here, refers to attempt to re-establish a connection in optical networks, which is being affected by a signal degrade or by the complete loss. Optical network service restorability (ONSR) relates to the efficiency of the restoration method applied. An optical network service (ONS) is defined as any kind of handling of optical signals originating from optical network clients [1]. Like other quality attributes (transmission, access, ...), the ONSR also varies with performance objectives of each single client network. High restorability may be required for clients handling real-time data, while computer communications for other data may tolerate higher connection blocking probabilities or long restoration times. We do not consider any time sensitive attributes of restoration, i.e. we assume that the restoration time is negligible.

Since the Quality-of-Service (QoS)-guarantee is the main issue for integration of optical networks into the existing network infrastructure, the optical network services are here classified according to the quality degree (QoS-guarantee) and restorability required. By using the QoS-routing method to set-up connections, a route capable of providing all necessary QoS-performances for transmission, routing, network management, economic efficiency and restoration is selected for every connection request to the optical layer [1]. We assume that restoration is needed each time the QoS is degraded. The blocking probability is here defined as probability that for a certain service call the required restorability and hence QoS cannot be provided.

RESTORATION METHODS

The original path that is established at the connection set-up is called the *working path*. In case of a fibre cut a network has to find an alternative temporary path, a *restoration path*, for all the affected services of the damaged link. If a restoration path is pre-reserved either exclusively for a connection or by sharing, it is also called a *spare path*.

In this paper, we distinguish between two restoration schemes depending on restoration end-points of a connection. One is the restoration between the working path-terminating nodes of the failed path, *path-restoration* (PR), the other is the restoration between the terminating nodes of a failed link, *link-restoration* (LR).

In both of these methods either *dynamic-* or *static (pre-planned) restoration* techniques can be applied [2]. With *dynamic restoration* techniques the spare entities in the case of link failure are dynamically searched. In this case the complex routing algorithm must be applied. The main benefits of dynamic restoration methods are robustness to multiple link failures and a simple *a posteriori* network expansion. *Static restoration* techniques reserve spare entities for a connection at the moment of a connection set-up. Since no routing is necessary at the moment of failure, this technique is faster than dynamic restoration. However, the network utilisation is diminishing, because of large number of spare resources reserved.

In this paper, for every existing service a specific restoration method for link failures is assigned. *Dynamic Link Restoration (DLR*) establishes spare paths between link-terminating nodes of a failed link. For all affected services using a failed link a connection for restoration must be found. For *Dynamic Path Restoration (DPR)* restoration paths between path-terminating nodes of all affected paths must be found. The number of optical paths to be restored is directly proportional to the traffic on a failed link. *Static LR (SLR)* is based on pre-planned *1:1* spare links that are assigned at the connection set-up. This is supposed to be necessary only for very limited number of services requiring extremely high restorability. Because of the large waste of capacities, *Static PR (SPR*), based on pre-planned *1:1* spare paths is preferred. It uses the link disjoint paths algorithm, where network graph transforms for path/link-terminating nodes are applied. This algorithm will be explained in more details in the next section.

As a trade-off between fair network utilisation and restorability the methods *Shared Static LR (SSLR)* and *Shared Static PR (SSPR*) can be used. The SSLR-method means that a certain wavelength is assigned as a spare for more than one spare path on a link. If a failure occurs, only one spare path can be established per shared wavelength. The SSPR-methods means that the resources used for a certain spare path should be preferably used when assigning another spare paths.

DEFINITION OF RESTORABILITY

The restoration ratio or restorability of a service S_i is the measure of efficiency of a restoration method. The ***restorability, r_i***, (*i* indicates the service quality degree) is here defined as:

$$r_i = \frac{\text{successfully restored services } S_i}{\text{number of attempts to restore a service } S_i} \quad (1)$$

For restoration purposes it will be important to find two shortest link-disjoint paths between two nodes. The motivation to find an algorithm that provides link disjoint paths is explained with Figure 1. In Figure 1a, the spare path is completely separated from the working one. However, as furthermore shown in Figure 1b, if at least one link of the affected path use the same duct as a link of the working path, the recovery of link failure between the nodes 3 and 7 is not possible. This comes from the fact that mostly all fibres that use the same duct are damaged in case of a fibre cut. For that purpose, it is advantageous to find link disjoint paths.

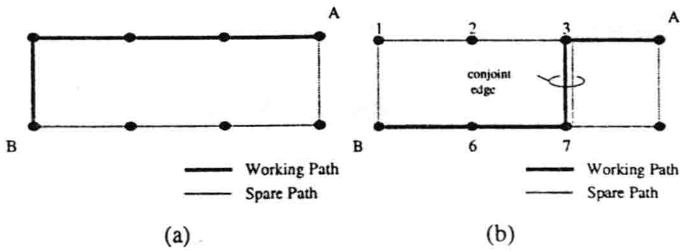

Figure 1 An example where working and spare path are two link disjoint (a) or conjoint (b) paths

It is not always possible to find a link disjoint path for a certain network topology. For that purpose, we first have to test the network topology, if a link disjoint path exists. This is strongly related to the definition of reliable networks. The fundamental requirement for network reliability can be expressed as the condition that any two subparts of the graph must be connected by at least two links [3]. This is the guarantee that in the case of a single link failure the network remains connected and restoration paths can be established along alternative physical paths. For that reason the nodal degree for every node must be greater or equal 2.

Note that the condition must be modified for survivability, if a node-failure occurs. When designing survivable networks we postulate the following:

> *Any two subparts of a graph must be connected by at least two disjoint links, and, if there is more than one node in a sub-graph, at least two links must originate from different nodes.*

For that purpose, not only link disjoint path algorithms, but also node disjoint path algorithms are necessary. According to that, we can say that a bi-directional bus-topology represents a non-survivable graph. On the other side, a bi-directional ring-topology is survivable for link and node failures.

Now the *link disjoint path algorithm (LDPA)* is presented in more detail. Let us assume that for a pre-planned restoration technique it is necessary to find a link-disjoint path for the working path in the network $G(V, E)$, where $V = \{v_1, v_2, .., v_N\}$ is representing N nodes and $E = \{e_1, e_2, .., e_L\}$ stays for L links.

Assume that the algorithm is shown for the path-terminating nodes *src* (source) and *dest* (destination). The routing algorithm *routing(src, dest, G)*, used here is based on routing with QoS, where for every service call a path capable of providing a QoS guarantee is chosen. The services are classified according to the quality degree to be provided for them. As a shortest path algorithm we use the Dijkstra's shortest path algorithm [4].

In Figure 2 it is shown how the link-disjoint path algorithm is accomplished. First a shortest path from node *src* to node *dest*, called $path_1 = routing(src, dest, G)$, is found. The connection $path_1$ between the source and destination node will be established for the connection set-up in a common way. Then in the next step all links of the graph G between the intermediate nodes of the $path_1$ are removed, so that conjoint links are not longer available. Now the graph has to be transformed into a graph G', $G' = G \setminus \{e_i\}$, $\forall e_i \in path_1$. For the transformed path G', the second link disjoint shortest path $path_2 = routing(src, dest, G')$ must be found. With the last step, the path $path_2$ is finally the link-disjoint path.

The same algorithm can be applied for finding the restoration path for a one link of a working path, so that the path-terminating nodes *src* and *dest* are replaced by the link-terminating nodes.

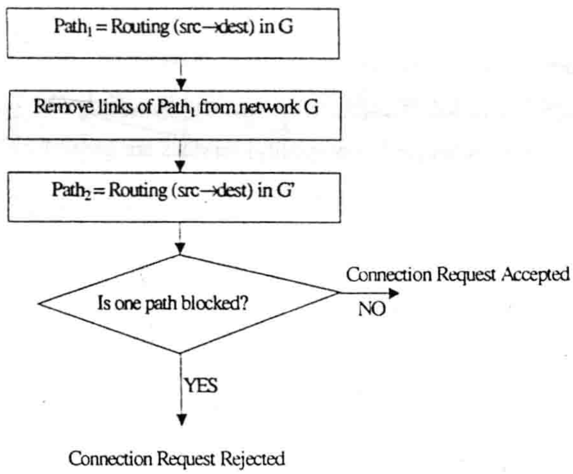

Figure 2 LDP-algorithm

PERFORMANCE STUDY AND SIMULATION RESULTS

For the numerical examples shown in this section, we use the basic assumptions of circuit switching networks: