CAMBRIDGE
Cambridge University Press
0521853885 - Survivability and Traffic Grooming in WDM Optical Networks
Arun K. Somani
Frontmatter
More information

SURVIVABILITY AND TRAFFIC GROOMING IN WDM OPTICAL NETWORKS

The advent of fiber optic transmission systems and wavelength-division multiplexing (WDM) have led to a dramatic increase in the usable bandwidth of single-fiber systems. This book provides detailed coverage of survivability (dealing with the risk of losing large volumes of traffic data due to a failure of a node or a single fiber span) and traffic grooming (managing the increased complexity of smaller user requests over high-capacity data pipes), both of which are key issues in modern optical networks.

A framework is developed to deal with these problems in wide area networks, where the topology used to service various high-bandwidth (but still small in relation to the capacity of the fiber) systems evolves toward making use of a general mesh. Effective solutions, exploiting complex optimization techniques and heuristic methods are presented to keep network problems tractable. Newer networking technologies and efficient design methodologies are also described.

This book is suitable for researchers in optical fiber networking and designers of survivable networks. It would also be ideal for a graduate course on optical networking.

Arun K. Somani is the Jerry R. Junkins Endowed Chair Professor of Electrical and Computer Engineering at Iowa State University. His research interests are in the area of fault-tolerant computing, computer interconnection networks, WDM-based optical networking, and parallel computer system architecture. He has served as an IEEE distinguished visitor and an IEEE distinguished tutorial speaker. He has been elected a Fellow of the IEEE for his contributions to the theory and applications of computer networks.

© Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
0521853885 - Survivability and Traffic Grooming in WDM Optical Networks
Arun K. Somani
Frontmatter
More information

SURVIVABILITY AND TRAFFIC GROOMING IN WDM OPTICAL NETWORKS

ARUN K. SOMANI

CAMBRIDGE
UNIVERSITY PRESS

© Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
0521853885 - Survivability and Traffic Grooming in WDM Optical Networks
Arun K. Somani
Frontmatter
More information

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, São Paulo

Cambridge University Press
The Edinburgh Building, Cambridge CB2 2RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521853880

© Cambridge University Press 2006

This publication is in copyright. Subject to statutory exception
and to the provisions of relevant collective licensing agreements,
no reproduction of any part may take place without
the written permission of Cambridge University Press.

First published 2006

Printed in the United Kingdom at the University Press, Cambridge

A catalog record for this publication is available from the British Library

Library of Congress Cataloging in Publication data

ISBN-13 978-0-521-85388-0 hardback
ISBN-10 0-521-85388-5 hardback

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party internet websites referred to in this publication, and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.

CAMBRIDGE

Cambridge University Press
0521853885 - Survivability and Traffic Grooming in WDM Optical Networks
Arun K. Somani
Frontmatter
More information

This book is dedicated to my parents, who have been an inspiration towards my achievements in life, and to all my students who helped turn my dream into a reality and my family who supported me unconditionally.

© Cambridge University Press www.cambridge.org

Contents

© Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
0521853885 - Survivability and Traffic Grooming in WDM Optical Networks
Arun K. Somani
Frontmatter
More information

© Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
0521853885 - Survivability and Traffic Grooming in WDM Optical Networks
Arun K. Somani
Frontmatter
More information

© Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
0521853885 - Survivability and Traffic Grooming in WDM Optical Networks
Arun K. Somani
Frontmatter
More information

© Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
0521853885 - Survivability and Traffic Grooming in WDM Optical Networks
Arun K. Somani
Frontmatter
More information

© Cambridge University Press www.cambridge.org

Preface

Before the 1970s, networks were primarily used to carry voice or telephone calls over circuit-switched networks. Failures and service outages in such transport networks were handled mainly at the circuit layer, and many a time manually. Most of the remedial actions included routing of the call by manual configuration of switches by network operators. Over time the capacity of the transport networks increased, data overlay networks were created and a large number of end-users instituted private voice and packet networks.

With the advent of fiber optic transmission systems and eventually wavelength-division multiplexing (WDM) the bandwidth of a single fiber soared. With increasing deployment of fibers in networks, the risk of losing large volumes of traffic due to a span cut or a node failure has also increased tremendously. In the 1990s Bellcore developed the SONET (synchronous optical network) standard and standardized the concept of self-healing rings. It was soon followed by the equivalent standard named SDH (synchronous digital hierarchy) in Europe. This appeared to be the final solution. Many service providers could replace all of their cumbersome and expensive point-to-point transmission systems with a few multi-node, self-healing SONET rings. Many carriers joined the SONET ring bandwagon.

With further developments in technology, more and more mesh-network topologies started emerging. Failure management still remained a part of the solution and recovering from them remained a challenging issue. It soon started to fuel the everlasting question that still prevails to this day: which is a better option, ring-based or mesh-based restoration? Over the years, as the traffic increased a mesh-based approach seemed to be a more viable option for providing restoration, compared to a traditional ring network. There are different tradeoffs between ring and mesh restoration. In a ring network, once the network is installed the restoration is automatic. In contrast, in a mesh network, most of the control is in the hands of a centralized control system, and hence it makes the control very complicated. This motivated the need for intelligent network elements which are capable of

© Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
0521853885 - Survivability and Traffic Grooming in WDM Optical Networks
Arun K. Somani
Frontmatter
More information

distributed routing, detecting failures of the links and passing topology update information amongst adjoining nodes using variations of link state protocols.

Another important element of the architecture is when and how much to do to recover at the time of establishing a connection. The range of options varies from identifying and provisioning the resources for recovery to take care of failure at the time of establishing the connection, to identifying all resources to recover when a failure occurs. The former is called protection and the latter is an extreme in restoration. In between options include identifying an alternate path only for a connection being established, identifying an alternate path and resources to be used on the path but not activate the path, or even activating the resources but not using them. Each option presents a different cost and impact on functionality of the network.

In present-day networks, SONET rings are more prevalent in metropolitan networks, where there is less geographic diversity, whereas mesh-based networks are more common in ultra-long-haul networks covering areas of vast geographical variations. Also, as optical cross-connects and WDM switching technologies mature, mesh-based restoration for pure optically switched networks are of increased interest because of the reduced costs of optical–electrical conversion and the economics of scale for integration of WDM and electronics.

Another important debate that has not been settled is which layer in networking should be responsible for protection and/or restoration. At the present time the internet protocol (IP) is the dominant mode of internetworking. The IP layer has its own protection and restoration strategy. For each destination, a source may have many possible paths and may choose to have a preferred path for routing packets to that destination. At the optical or physical network level, a network designer may adopt a strategy to recover from a complete fiber failure. On the other hand, many IP routes may be routed through the same fiber as a fiber does support many channels, each being used for a different IP route. Thus, a single fiber failure may result in multiple IP route failures. Moreover, optical networks use the concept of a virtual topology, in which most commonly used routes may be created using a concatenation of channels on multiple fibers. The IP layer may not even be aware of how the physical network has been utilized to create a virtual topology. Hence IP routing and restoration have some pitfalls. It is not clear which strategy or a combination of the two is better. It is believed by many researchers that protection/restoration at the WDM layer is more advantageous, but this is disputed by those who prefer IP protection/restoration.

This brings us to one of the two most important contributions of this book. We attempt to provide a brief overview of different optical networking trends and technologies followed by different network design and restoration architectures in mesh-restorable optical networks. Several chapters are devoted to studying

© Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
0521853885 - Survivability and Traffic Grooming in WDM Optical Networks
Arun K. Somani
Frontmatter
More information

various protection and restoration architectures, methods to model the problem, and algorithms to design functionality and operational aspects, and to study the performance of various schemes.

Another important problem in optical fiber networks with wavelength-division multiplexing is that of traffic grooming. The capacity of a single wavelength channel has been increasing constantly, reaching the level of 10–40 GHz/channel. At the same time individual user requirements are not increasing at the same pace, although the overall number of users and applications are increasingly dramatically. Thus, it is important to accommodate all the applications while utilizing the resources efficiently. The traffic grooming problem presents a whole new set of challenging problems.

The second half of the book focuses on traffic grooming. Traffic grooming is a technique for multiplexing different subwavelength capacity traffic requirements onto a single wavelength so that the wavelength and hence the capacity requirements of the whole network are minimized.

This book is written with two main communities in mind.

One of them consists of my colleagues in industry, research scientists, technology planners, network designers, and also corporate research laboratories. They are incessantly striving to access the economics of different architectural decisions and standards devolvement. Network operators are in a fiercely competitive market, striving for more and more productivity. Mesh networking studied in this book provides them with great productivity enhancements through greater network efficiencies and flexibility. Developers of network modeling, simulation, and network planning would be interested in many of the ideas presented in this book. Incorporating capabilities to design all types of architecture alternatives, and accessing the merits and demerits of each chosen alternative, the book fuels the interest of different network researchers.

The second main community who would benefit from this book are graduate-level teachers and researchers who want a self-contained volume to derive insights into aspects of transport network design and also to use this to teach a graduate-level course on optical networking. I expect both communities to benefit equally. Any designer of a new graduate course will hopefully continuously upgrade the material with more advanced developments as the technology improves.

In the following, the flow of the contents in the book is explained.

Chapters 1 and 2 serve as introductory chapters to networking using fiber optics technology and the rest of the book. Since the book specializes on two most important topics, understanding the rest of the concept is important. For that reason, these chapters serve as an introduction to wavelength-division multiplexing, broadcast-and-select-network designs, and different optical networking trends and technology. They also introduce several interesting aspects and issues in the design

© Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
0521853885 - Survivability and Traffic Grooming in WDM Optical Networks
Arun K. Somani
Frontmatter
More information

of such networks, which include the routing and wavelength assignment problems, optical packet switching and optical burst switching, traffic grooming and survivability in mesh restorable optical networks, and survivable traffic grooming in optical networks.

The book then moves on to discuss different restoration approaches and also the upgradeable network design problem. The whole concept is treated within a survivability framework. Mesh restoration architectures have natural ties into the network design problem. It can be viewed as a network design and network operation problem. The problem can be formulated using different scenarios and that subject is dealt with in the next chapter. Different formulations and heuristic approaches to solving the network design problems are discussed in Chapter 3. Chapter 4 deals with an alternate approach, called the p-cycle or protection cycle. This strategy allows the use of similar protection algorithms to those designed for ring networks in mesh-like architectures.

Chapter 5 concentrates on network operation. There are two important goals in network operation. The network can be optimized to use minimal capacity out of that available to serve the offered demand, assuming that the demands are not greater than the capacity. The goal here is to keep as much capacity free as possible to accommodate future requests. Alternately, the demands offered may be more than the available capacity. In that case, the goal is to optimize the operation and accept those requests that would maximize the service providers' gain. Depending on the gain matrix chosen, the optimization can be tuned to serve a specific aspect. The details of such operational optimizations are discussed in the form of the capacity minimization and the revenue maximization subproblems.

The optimization problems formulated in Chapter 5 are complex and difficult to solve in real time. We continue to discuss different relaxation techniques that can be applied to solve the integer linear programming (ILP) problems in Chapter 6. The goal here is to adopt those techniques that will result in a near-optimal solution while minimizing the required computation time. Some insight into the formulation is developed and used to derive near-optimal or optimal solutions while keeping the commutation time under control for near real-time and real-time on-line applications.

In Chapter 7, we discuss how to tolerate multiple link failures in a network. The problem is reviewed in detail and some solutions are studied. We also present an ILP approach to solve the dual-link failure problem in a WDM network. Several other techniques for solving the multi-link failure protection and restoration problem are also presented.

In the following chapter, Chapter 8, we present another approach called the subgraph-based routing strategy in mesh-restorable WDM optical networks. In this

© Cambridge University Press www.cambridge.org

Cambridge University Press
0521853885 - Survivability and Traffic Grooming in WDM Optical Networks
Arun K. Somani
Frontmatter
More information

scheme no resources are reserved for protection. However, provision is made to make sure that all resources are available when an actual failure indeed occurs. It is demonstrated how subgraph routing can be used to protect a network against multiple-link and node group failures.

Chapter 9 introduces the concept of traffic grooming in WDM optical networks. Both static and dynamic traffic grooming concepts are presented. The chapter also discusses techniques for static traffic grooming in rings and presents the advantages of and issues in traffic grooming in WDM rings.

Chapter 10 presents a model to study the advantages of traffic grooming and quantifies the gains of traffic grooming. An analytical model of a WDM grooming network is presented for grooming on a single wavelength on a single- and a multihop path. The model also discusses the type of network where all or some of the nodes in the network may be capable of grooming.

One of the important issues in any traffic grooming is that of fairness. Since users may request different capacities, it is important that all requests are handled fairly based on chosen criteria. Although fairness means different things to different people, we present a model of fairness in Chapter 11 that we use in this work and evaluate the fairness of various routing and wavelength assignment algorithms used in WDM grooming networks.

Chapters 12 and 13 bring the two topics, survivability and traffic grooming, together. In Chapter 12, we discuss survivable grooming network design. Both routing and wavelength selection issues for survivable traffic grooming are presented and solutions are developed to utilize resources effectively in such networks. Chapter 13 deals with the design of networks that support static traffic grooming with survivability.

In the second part of the second topic, a new framework for dealing with traffic grooming is presented. This framework, called a trunk-switched network, presents a methodology to represent and analyze traffic grooming. The framework is a powerful one, which can support modeling of various traffic grooming mechanisms and analyze them. Chapter 14 presents the framework and modeling methodology for a WDM traffic grooming network. The next chapter, Chapter 15, is devoted to use of the network for performance analysis. Chapter 16 is devoted to validating the model and includes several examples to demonstrate the applications of trunk-switched WDM grooming networks. Both sparse and dense networks (defined based on the number of nodes that support traffic grooming) as well as homogeneous and heterogeneous networks (defined based on the type of grooming nodes being identical or different) are managed.

Chapter 17 is devoted to traffic routing and wavelength assignment algorithms in a traffic grooming network. Several algorithms are presented and analyzed.

© Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
0521853885 - Survivability and Traffic Grooming in WDM Optical Networks
Arun K. Somani
Frontmatter
More information

Chapter 18 presents traffic grooming in an IP-over-WDM network. This is an important area as both IP and WDM have to eventually work together. Algorithms to route IP traffic efficiently over a WDM network are presented and analyzed.

The final chapter, Chapter 19, presents an innovative technique called the light trail architecture, which is used for traffic grooming in WDM optical networks for local and metropolitan areas and has the potential to integrate with wide area networking. It also discusses how restoration can be achieved in the light trail architecture and presents an ILP formulation for the survivable light trail design problem.

Additional material in a few appendices would help researchers from various communities to develop interest in the topic of survivability and traffic grooming in optical networks. The goal is to create a highly useful and interesting book that is imbued with new options and insights for industry and academia to enjoy and benefit from.

© Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
0521853885 - Survivability and Traffic Grooming in WDM Optical Networks
Arun K. Somani
Frontmatter
More information

Acknowledgments

A work of this magnitude is a result of encouragement from and the efforts of many people.

First, there has to be inspiration. My father, a visionary, had provided me with a gift that I only appreciated after he passed away. Right from the beginning, he kept me focused on achieving the best and continuing to strive until a goal is achieved. He pushed me into situations where the chances of failures were high and encouraged me to succeed. Part of the reason for him probably was that he had to give up his studies sooner than he wanted or needed to. He fulfilled that dream of his through his children and felt his success through us, his children. I have been a tutor right from my third/fourth grade. Not only encouraging us in academics, he also continuously strived to make us good citizens and to help others.

Whenever he felt weak, such as when I had to leave home for college, my mother took charge. The encouragement from the two of them has resulted in what I am today. I am indebted to them.

And then my students, who were always full partners in the work I produced. I was blessed with excellent graduate students who always challenged me and kept me on my toes. Although I had many students working with me in many different areas, this work is mainly representative of the work I performed with Suresh Subramaniam, Ling Li, Sashisekhran Thiagarajan, Srinivasan Ramasubramanian, Murari Sridharan, Tao Wu, Jing Fang, Pallab Datta, Mike Fredericks, Nathan Vanderhorn, Wensheng He, Srivatsan Balasubramaniam, Nitin Jose, and Yana Ong, who have contributed to this work in many ways. The contribution made by each of them is great. They deserve a rich appreciation.

Among my colleagues, I was blessed to have worked with many good people. James A. Meditch initially inspired me to start looking at problems in this area. Murat Azizoglu was a great colleague to work with. Later on Ahmed Kamal, Robert Weber, and Mani Mina have been great allies. I never hesitated in asking them for any help, academic or otherwise, which I always received. Thanks go to all of them.

© Cambridge University Press www.cambridge.org

Cambridge
Cambridge University Press
0521853885 - Survivability and Traffic Grooming in WDM Optical Networks
Arun K. Somani
Frontmatter
More information

Finally, my wife, Manju, who never questions me when I return from the office and always tolerates any amount of my work frustration. Religiously she packs my lunch every morning at 7:30 a.m. and reminds me every evening, including most weekends, that it is 7:00 p.m. and I might be hungry. She always took care of the kids and provided the support they needed from both of us. My kids love me unconditionally, irrespective of the amount of time I found for them.

My special thanks to Pallab who has really assisted me in organizing the material in the book into its current shape. Without him, I have no idea when I would have been able to finish it.

It has been a real blessing to be surrounded by friends, colleagues, students, and family as I have. I am indeed thankful to all of them.

© Cambridge University Press www.cambridge.org