# HANDBOOK OF OPTIMIZATION IN TELECOMMUNICATIONS

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This book is dedicated to
Lucia and Rosemary.

# Contents

# Preface

Telecommunications has had a major impact in all aspects of life in the last century. There is little doubt that the transformation from the industrial age to the information age has been fundamentally influenced by advances in telecommunications. What sounded like science fiction just a few years ago is now reality. For example, in 1945, Arthur C. Clarke envisioned the integration of rockets and wireless communications in a system of orbiting space stations to relay radio signals around the world. Only twenty years later, Intelsat, the international satellite telecommunications organization, successfully placed the Early Bird satellite over the Atlantic Ocean.

Innovation and growth in telecommunications have been staggering. In 1927, AT&T introduced transatlantic telephone service, via radio, between the U.S. and London. The service had capacity for one call at a time and cost $75 for a three-minute call. Customer dialing for long distance domestic calls was introduced in 1951, and international calls only in 1970. The first fiber optic cable in a commercial communication system was put in place in 1977. Today, international calls cost consumers only a few cents a minute.

The International Telecommunication Union (ITC) estimates that the number of landlines worldwide grew from about 689 million in 1995 to over 1 billion in 2001. In the developing world, the growth was much greater. In China, for example, the number of lines quadrupled from 41 to 179 million in those six years. As recently as twenty years ago, personal wireless communication was limited to a handful of government and military officials. The first commercial cellular telephone system in the U.S. was opened in 1983. Now, it has spread all over the world. Again, in the period from 1995 to 2001, the number of mobile phones worldwide grew from about 91 million to almost a billion. In 64 developing countries, the number of mobile lines grew a hundred-fold in that period. In many countries, there are more wireless lines than wire lines. Wireless penetration in Europe is expected to reach 100% by 2007.

Broadband was unknown only ten years ago. In 2005, nearly half of the U.S. population had broadband Internet access. In some U.S. markets, nearly 70% of homes had broadband. In March 2005, according to the website `internetworldstats.com`, Sweden had the highest Internet penetration with about 74% of its population having access. Regionally, North America had the highest penetration (64%). However, only

about 13% of the world's population could access the Internet (in Africa this value was only 1.5%), suggesting that there is still a long road ahead in the deployment of telecommunication systems around the world.

In the early days, telecommunication networks carried mainly voice traffic. With time, an increasing portion of traffic consisted of data. By 2000, the volume of data traffic on AT&T's network was greater than the volume of voice traffic. With voice over IP (VOIP), voice has become data and soon only data will be transported on telecommunication networks.

Optimization problems are abundant in the telecommunications industry. The successful solution of these problems has played an important role in the development of telecommunications and its widespread use. Optimization problems arise in the design of telecommunication systems, and in their operation.

This book brings together experts from around the world who use optimization to solve problems that arise in telecommunications. The editors made an effort to cover recent optimization developments that are frequently applied to telecommunications, and a spectrum of topics, such as planning and design of telecommunication networks, routing, network protection, grooming, restoration, wireless communications, network location and assignment problems, Internet protocol, world wide web, and stochastic issues in telecommunications. It is our objective to provide a reference tool for the increasing number of scientists and engineers in telecommunications who depend upon optimization in some way. Target readers will include students, researchers, and practitioners in engineering, computer science, statistics, operations research, and mathematics.

Each chapter in the handbook is of an expository, but also of a scholarly nature, and includes a brief overview of the state-of-the-art thinking relative to the topic, as well as pointers to the key references in the field. It is our expectation that specialists as well as nonspecialists will find the chapters stimulating and helpful.

The handbook is organized in six parts.

- Part I deals with basic optimization algorithms, including linear, integer, and nonlinear programming, network and multicommodity flow, and shortest path algorithms, metaheuristics, and Lagrangian relax-and-cut algorithms.

- Part II focuses on planning and design. This includes chapters on network planning, multicommodity flow and decomposition, network design, ring network design, access network design, distribution network design, survivable network design, location problems, Steiner tree problems, hop-constrained minimum spanning tree problem, quality of service, and pricing and equilibrium in communication networks.

- Part III addresses routing, with chapters on dynamic routing networks, routing and wavelength assignment, optimization in IP networks, and optimization of multicast trees.

- Part IV covers reliability, restoration, and grooming. This includes chapters on optimization of network reliability, stochastic optimization, network restoration, and network grooming.

- Part V focuses on issues arising in wireless telecommunications. This includes chapters on graph domination, coloring, and cliques, optimization in wireless networks, optimization for planning cellular networks, and dynamic load balancing in CDMA networks.

- Finally, Part VI deals with the web and beyond telecommunication networks, including optimization issues in web search engines, e-commerce, combinatorial auctions, and supernetworks.

Bibliographies are given at the end of each chapter. For ease of reference, the bibliographies at the ends of chapters have been compiled into a single HTML document which can be found online at `http://www.springer.com/0-387-30662-5`.

We would like to take this opportunity to thank the contributors, the reviewers, and the publisher for helping us to complete this handbook. We would also like to thank AT&T Labs Research and the National Science Foundation for partial support of this project.

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