Preface

The increasing complexity of telecommunication networks puts at the forefront the problem of developing adequate mathematical models for them. The main goals are finding their characteristics, solving the problems of their optimization subject to chosen criteria, and developing the corresponding control algorithms.

The basic mathematical tool that allows us to build both adequate analytical and numerical models of telecommunication networks is queueing theory. The core of this theory was founded more than 100 years ago in the pioneering work of Agner Erlang. He studied only the then recently telephony systems, but since then the models and methods of queueing theory have been widely used for studying service processes in various branches of science and industry, among them economics, manufacturing systems, military science, and transportation.

Remarkably, the most important reason for studying queueing theory, now as well as 100 years ago, is telecommunication networks. However, there are many distinctions between the models of the past and modern telecommunication networks. We should first note that in classical Erlang's models, it was assumed that calls do not differ from each other, i.e., calls are identical. In other words, early telecommunication networks were queueing systems with single traffic. However, in modern telecommunication networks, the calls (messages) essentially differ from each other with respect to some parameters. For example, calls can vary in arrival intensity and/or processing time, in the level of priorities, in the service mechanism, etc.

These facts show that classical queueing models with single traffic can serve only as rough (approximate) mathematical models of modern telecommunication networks. The functioning of modern telecommunication networks can be described only by means of queueing models with several types of traffic—adequate models of modern telecommunication networks are multidimensional ones. Such kinds of models are especially useful for studying integrated networks in which real-time calls, for voice, video, etc., and non-real-time calls, for data, fax, e-mail, etc., are handled.

Queueing models with single traffic are well studied, and they are described in well-known textbooks and monographs, but multidimensional queueing models are insufficiently studied, and there are only a few monographs on this theme. This book is devoted to the problem of applying multidimensional Markov models in modern telecommunication networks.

Unlike one-dimensional models, using exact and simple formulas to calculate the quality-of-service (QoS) metrics of multidimensional models is usually impossible. This is explained by the fact that in many cases the appropriate system of global balance equations (SGBE) for the steady-state probabilities has no explicit solutions—e.g., the solution in the multiplicative form. In such cases, various numerical (exact or approximate) methods must be used.

The classical approach to calculating the steady-state probabilities is based on the theory of multidimensional generating functions. However, there are well-known associated computational difficulties because we must solve systems of partial differential equations and equations for boundary states as well.

The alternative and more effective approach based on the use of SGBE for calculating the QoS metrics of multidimensional Markov models contains the following stages. First of all, note that this approach is used mainly for models with finite dimension of state space.

In the first stage, the state of the system is defined, and the set of all possible states (state space) is formed. As a rule, the system's state is described by a vector of corresponding dimension. In the second stage, an infinitesimal matrix (Q-matrix) of the appropriate multidimensional Markov chain (MC) is constructed. It is known that constructing the Q-matrix is enough to develop the SGBE. In the third stage, steady-state probabilities are found from the SGBE. In the final stage, the desired QoS metrics are calculated via steady-state probabilities, i.e., the QoS metrics are determined as appropriate marginal distributions of the initial multidimensional MC. By taking into account the unique property of Markov models, it is possible that the stationary probability of a state represents part of the sojourn time of the system in a corresponding state for a large supervision time interval.

The main problem in this approach is solving the SGBE, i.e., realizing the third stage, since the growing traffic and the increasing number of channels, as well as the buffer sizes of the corresponding telecommunication network, rapidly lead to an increase in the dimension of the state space. In some cases, by using the specific structure of a corresponding Q-matrix, it is possible to simplify this problem. So, for instance, it becomes simpler for networks that are described by models of reversible Markov chains since for such models the analytical solution in multiplicative form can be obtained. If the analytical solution of the SGBE is not available, as mentioned above, then various numerical methods are used. In this book, we use both approaches to investigate models of telecommunication networks.

The book consists of five chapters. In Chap. 1, both single-rate and multi-rate Erlang's models are considered, and we examine known computational algorithms to calculate their QoS metrics. Here also we propose hybrid access schemes in mono-service cellular networks without buffers, and we develop both exact and approximate methods to calculate the QoS metrics of such access schemes. In Chap. 2, we develop an analytical method to investigate the models of multi-rate

Erlang's models with randomized access schemes. We also consider analytical methods to study the models of multiservice cellular networks with various partition schemes of common radio channels. In Chap. 3, we investigate models of mono-service cellular networks. Two types of models are considered: models with either finite or infinite buffers for both types of new and handover calls and retrial models. Numerical algorithms to calculate their QoS metrics are developed. We investigate models of multiservice cellular networks with buffers in Chap. 4. Finally, in Chap. 5, we examine models of packet-switching networks with priorities. Here we examine in detail nonclassical priority schemes with multiple space and time priorities as well as jump priorities.

Each chapter of the book contains results from numerical experiments carried out using the developed algorithms, and each chapter contains comments and references that allow the reader to understand the current situation in the corresponding areas of research.

This book is recommended for researchers engaged with the mathematical theory of teletraffic. It will be useful for graduate and PhD students in informatics and applied mathematics as well as other fields.

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http://www.springer.com/978-3-319-08668-2

Multidimensional Queueing Models in Telecommunication Networks
Melikov, A.; Ponomarenko, L.
2014, XII, 190 p. 70 illus., Hardcover
ISBN: 978-3-319-08668-2