Performance Analysis and Optimization of Multi-Traffic on Communication Networks

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Preface

Rapidly growing demand for telecommunication services and information interchange has led to communication becoming one of the most dynamic branches of the infrastructure of modern society. On the boundary between the twentieth and twenty-first century the convergence of telecommunication, computer and information technologies and also the merging of corresponding industries begun and is proceeding.

The teletraffic theory has become in the last few years an independent scientific discipline representing a set of probabilistic methods to solve problems of planning and optimization of telecommunication systems. For the solution of problems that arise in the specified branch of engineering practice both analytical and numerical methods of modeling are widely used. However, the application areas of analytical methods are essentially limited due to the complexity of models of modern teletraffic systems. Therefore, in modern teletraffic theory there is a special urgency for the development of effective numerical methods of research. Specific features of various teletraffic systems aggravate problems of development of universal numerical methods.

The functioning of complex probabilistic systems is described by mathematical models considering the basic specific features of the work of these systems. In such mathematical models various classes of stochastic processes are used.

The most effective mathematical tool for analysis has been developed for systems in which functioning is described by homogeneous Markov processes (or chains). The basic characteristics of Markov models are determined by solution of systems of linear equations (algebraic, differential, or integral). However, the assumption concerning the Markov property of investigated systems is rather limiting, therefore as mathematical models of real systems more general classes of stochastic processes are used. At the same time, sometimes it is possible to achieve Markov property for a model by complicating state space of the model process.

The tendency for maximal accuracy in the description of functioning of real systems leads to the fact that corresponding mathematical models have become more and more complex. Thus, their mathematical analysis becomes complicated and the tool for the analysis becomes cumbersome and often inaccessible in an engineering practice.

The basic difficulty in modeling and analysis of complex telecommunication systems is shown by the unreasonable increase in the number of the various states which leads to the practical immensity of a model. An actual problem in the mathematical theory of teletraffic is overcoming a basic difficulty – the large dimension of state space of the model ("curse of dimensionality").

Here the problem consists of using the large number of possible states of a system as a positive factor essentially allowing simplification of its analysis (similarly to statistical physics where the basic laws of large-scale physical systems represent the interaction of the ultimately huge number of particles forming them).

The most radical approach to overcoming complexity in the analysis of a real system consists of construction of a simpler merged system whose analysis is essentially easier than the real analysis, and the basic characteristics can be accepted as characteristics of the latter.

The idea of researching a complex system via its parts at the level of subsystems with a subsequent transition to the system underlies methods of solution of various problems. Corresponding methods are developed in essence to find solutions for large systems of algebraic equations. Thus, the main point here is the fact that the final solution of the system in its parts appears to be the exact solution of the initial system of equations. However, the mentioned methods which have undoubtedly proved their importance, appear in many cases to be insufficient for the solution of problems arising in an engineering practice.

In the present book methods for the merging of state space of complex teletraffic systems are uniformly developed. The idea of these methods is that the state space of a real system is split into a finite or infinite number of disjoint classes. The states of each of these classes are merged into one state. In the new merged state space a merged system whose functioning in a certain sense describes the functioning of the initial system is under construction.

The developed numerical methods can be applied to research of both classical models of integrated voice/data cellular wireless networks (CWN) and multi-rate models of multimedia communication networks with an arbitrary number of heterogeneous calls. Thus, the efficiency of the offered methods is shown on concrete classes of teletraffic systems. It is important to note, that they can be successfully applied, also in other branches of engineering practice.

The book consists of two parts and an appendix. In Part I which consists of three chapters, the models of a CWN integrating voice and data calls are investigated. Unlike classical models here it is supposed that original calls and handover (handoff) calls can differ from each other in terms of time of occupation of radio channels of a cell. In Chap. 1 two-dimensional unbuffered models of the investigated CWN are examined using various multi-parametric call admission control (CAC) strategies. In Chap. 2 similar models are investigated in the presence of finite and infinite queues of heterogeneous calls, thus handover calls can have limited sojourn distribution in a cell. In the last chapter of this part, problems of improvement of Quality of Service (QoS) metrics are considered.

In Part II which consist of four chapters, the multi-rate queuing models of multimedia communication networks intended for transfer of diverse messages are investigated. In Chap. 4 effective algorithms for calculation of QoS metrics in such networks are developed for various CAC strategies. Thus it is supposed, that all calls are inelastic. In Chap. 5 mixed models in which joint service of inelastic and elastic calls is carried out are investigated. Thus, models of two types are examined: with discrete and continuous schemes of distribution of a bandwidth between elastic calls. In Chap. 6 the problems of parametric optimization of QoS metrics of heterogeneous calls in multimedia communication networks are investigated. In Chap. 7 problems of the application of methods of the Markov Decision Processes (MDP) in teletraffic systems are considered. First a general scheme of the application of MDP in investigated systems is shown and the exact and approximate methods of solution of corresponding optimization problems are described. Then problems of finding an optimal and sub-optimal CAC strategy in models of multimedia communication networks are described, thus here a criterion of efficiency is maximization of channel utilization.

In the appendix a new approximate method for calculation of models of teletraffic systems which are described by a two-dimensional Markov chain (2-D MC) is developed.

The reader should know the basics of the theory of telecommunications, queuing theory, numerical methods, and methods of mathematical programming at the graduate or advanced undergraduate level.

The book contains the original results of authors published over the last few years in known scientific journals and reported at representative international scientific conferences. Each chapter is accompanied by a comment and a reference list which when combined gives an almost complete representation of the modern state of research of the mathematical theory of teletraffic. The book will be useful to specialists in the field of telecommunication systems and also to students and post-graduate students of corresponding specialties.

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Contents

List of Acronyms and Abbreviations

BDP	Birth-and-Death Process;
BS	Base Station;
CAC	Call Admission Control;
CS	Complete Sharing;
CSE	Complete Sharing with Equalization;
CWN	Cellular Wireless Network;
FIFO	First-In-First-Out;
GC	Guard Channels;
GM	Generating Matrix;
MC	Markov Chain;
MDP	Markov Decision Process;
MRQ	Multi-Rate Queue;
MS	Mobile Subscriber;
MSC	Mobile Switching Center;
PB	Probability of Blocking;
PMA	Phase-Merging Algorithm;
QoS	Quality of Service;
SGBE	System of Global Balance Equations;
SGC	Special Group of Channels;
SLBE	System of Local Balance Equations;
TR	Trunk Reservation;
$I(A)$	Indicator function of the event A;
$P(A)$	Probability of the event A;
$\varnothing$	Empty set;
$\approx$	Approximate Equality;
$a := b$	a is defined by expression b;
$i = \overline{1,N}$	$1 \le i \le N$ or $i = 1, \ldots, N$;
$Int(x)$	Integer (or whole) part of x; $x^+ := max(0,x)$;
h-call	handover call;
hd-call	handover data call;
hv-call	handover voice call;
i-call	call of type i or call from the traffic of type i;

n-call	narrow-band call;
o-call	original call;
od-call	original data call;
ov-call	original voice call;
w-call	wide-band call;
$\lambda_h(\mu_h)$	arrival (service) rate of handover calls;
$\lambda_i(\mu_i)$	arrival (service) rate of type *i* calls;
$\lambda_n(\mu_n)$	arrival (service) rate of narrow-band calls;
$\lambda_o(\mu_o)$	arrival (service) rate of new calls;
$\lambda_w(\mu_w)$	arrival (service) rate of wide-band calls;
$v_h = \lambda_h/\mu_h$	load offered by h-calls;
$v_i = \lambda_i/\mu_i$	load offered by calls of type *i*;
$v_n = \lambda_n/\mu_n$	load offered by n-calls;
$v_o = \lambda_o/\mu_o$	load offered by o-calls;
$v_w = \lambda_w/\mu_w$	load offered by w-calls;
P_o	Probability of blocking of o-calls;
P_h	Probability of blocking (or dropping) of h-calls;
PB_i	Probability of blocking of calls of type *i*;
PB_n	Probability of blocking of n-calls;
PB_w	Probability of blocking of w-calls;
$p(x)$, $\pi(x)$, $\rho(x)$	Stationary probability of state *x*;
$x \to y$	Transition from state *x* to state *y*;
$q(x, y)$	Transition intensity from state *x* to state *y*;
$\delta_{i,j} = \begin{cases} 1, & \text{if } x > 0, \\ 0, & \text{if } x \le 0; \end{cases}$	Kronecker's symbols;
$\delta_{i,j} = \begin{cases} 1, & \text{if } i = j, \\ 0, & \text{if } i \neq j \end{cases}$	
$\theta_j(v,m)$	Stationary distribution of Erlang's model *M*/*M*/*m*/*0* with load of *v* Erl, $j = 0,1,\ldots,m$;
$E_B(v,m)$	Erlang's B-formula for the model *M*/*M*/*m*/*0* with load of *v* Erl;
$\boldsymbol{e}_i$	unit vector in direction *i* in a Euclidean space whose dimension is specified in each particular case.