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Applied Methods for some Planning and Analysis Problems in Telecommunications Networking

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Ph.D. Dissertation Summary

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1 Introduction

In the recent years, the telecommunications networking areas have been going through impressive evolutions and developments. With the focus on provisioning quality of services, new networking technologies, architectures, and functionalities have been proposed and prepared for eventual implementations and deployments.

As a natural consequence of this, many unsolved, or still not satisfactorily solved problems and tasks are subjects of further research and improvements. Among such favorite research issues, network planning and analytical performance evaluation are the two important themes dealt in this dissertation. Specifically, each theme is concerned with

- developing a practical planning method for the optimal designing tasks of a realistic network, and

- developing and evaluating numerical methods for queueing models applied to the analytical performance evaluation of telecommunication systems,

respectively.

In principle, it is very essential to design and dimension telecommunications networks in a proper way. On one hand, as much resources (e.g. link capacity) as possible should be involved in the would-be network to meet entirely the technical requirements and specifications (e.g. service-specific levels of QoS). On the other hand, from the economic point of view, the network to be deployed should remain as much cost-efficient as possible. Therefore, the need for planning methods keeping well the tradeoff between the beforementioned factors emerges. In connection with this issue, part of my research work is dealing with a practical planning method for the topological optimization of an ATM network to be built on top of the existing SDH infrastructure.

Another part of my research work belongs to the topics of analytical performance evaluation. The behavior and the performance of the networking entities to be put into real-life operation should be examined and evaluated in a thorough way to avoid an unnecessarily expensive implementation. This is where the analytical performance evaluation comes to the picture. Having a good and thorough performance evaluation will enable seeking the best balance between the network performance and the implementation cost. As a matter of fact, analytical performance evaluation quantitatively defines a set of relevant performance parameters of the systems in question and analytically assesses them by achieving an appropriate performance analysis. The goal is to acquire analytical results of performance measures of the given system and through them to make it tractable from the performance point of view.

In order to carry out the analytical evaluation, two-dimensional markovian processes are frequently utilized. My research work focuses on a subset of such markovian processes. Namely, attention is devoted to the class of QBD (Quasi Birth Death) processes and its extended version,

to which we refer under the name QBD-M[1] processes. The use of these processes is observed widespreadly as a modelling tool in the performance analysis covering issues of ATM technology, DiffServ architecture, mobile networks, computer systems etc. My research is concerned with the investigations and development of computational methods for the steady state analysis of the aforementioned Markov chains.

2   Research Objectives

The aim of my research work related to the planning issues is

- to give an exact formulation of the planning task, which aim is to implement and deploy an ATM network on top of the SDH infrastructure. The idea of utilizing the existing SDH resources stems from the economic point of view and sharply corresponds to the realistic strategy of networking providers;

- to propose a practical approach to solve this planning task in an easy-to-implement and efficient way, which results in an ATM network with optimal topology.

The aim of the research work related to analytical performance evaluation addresses the following issues:

- Although some efficient numerical methods have already been successfully developed for solving QBD processes, the lack of an overall comparison concerning the performance of different methods, including execution time, space requirement, numerical stability and accuracy, still remains. My research efforts are devoted to filling this gap and to make a proposal of what method is more advisable to use knowing system's parameters.

- The second goal achieved by the research work is to develop simple and efficient methods for the steady state analysis of QBD-M processes. Numerical aspects considered during the development include time and space complexity, numerical accuracy and numerical stability.

- In the remainder of the research work, analytical models are constructed for some telecommunications systems enabling their performance analysis. The aim is two-fold. On the one hand, the wide range of application of QBD-M processes is pointed out and illustrated. On the other hand, a comprehensive comparison of computational methods is carried out to investigate benefits and drawbacks of each method.

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[1]The name comes from Ram Chakka in earlier private communications between him and Tien V. Do

3 Research Methodology

3.1 Network planning

Network planning comprises the following steps in sequence [10]:

- Design issues determination: this is to clarify the incipient aspects and design tasks. For example, whether the would-be network is built on top of existing capabilities; which aspect should be the most important: network cost, its performance or manageability; what is the focused problem: node placement and sizing or link topology optimization etc.

- Input data collection: this is to gather traffic demands, QoS requirements, device characteristics etc.

- Design task formulation: this is a technical step which mathematically combines all the information retrieved in the previous steps in a consistent and systematical description.

- Design tool choice: according to the features of the formulated task, a quantitative method is developed for the design process.

- Design results presentation and assessment of the proposed design method

The network planning part of the thesis strictly applies to the aforementioned design concept. The idea of building an ATM network with optimal topology on top of the existing SDH structure for given demand traffic and QoS requirements represents the principle of the first two steps. In the third step, the layered network model [9] is considered. The formulated task proves an integer programming problem, which seems to be NP-hard. Therefore, in the fourth step heuristic algorithms have been utilized.

3.2 Analytical performance evaluation

Generally, analytical performance evaluation of any given system consists of two stages:

- **Modelling stage**: The background of analytical performance evaluation relies on queueing theory including both the steady state and transient analysis. The chosen queueing model is expected to capture the essential characteristics of the system as much as possible. At the same time, it should remain analytically tractable.

- **Analysis stage**: Once the queueing model has been adopted, its numerical analysis regarding to the steady state or/and the transient behaviour is carried out. Performance measures of interest are computed and evaluated.

In the analysis stage, the need for efficient numerical methods is really brought out. This is the motivation of the research work (analytical assessment and development of numerical methods for QBD and QBD-M processes) presented in the remained part of the thesis.

The research work relies firstly on the deep knowledge of the queueing models along with being aware of their existing methods. The background of queueing theory, matrix analytic and the use of basic numerical criteria are essentially utilized. The analytical results have been confirmed by both theoretical considerations and concrete numerical data.

4　New results

The Department of Telecommunications has a tight collaboration with the PKI Telecommunications Development Institute in the framework of the introduction of ATM technology in Hungary. Towards a smooth introduction, several development phases have been defined. In 1999, the public ATM network phase has been launched, where the purpose was to construct a country-wide ATM network. The participation in this development phase has resulted in the scientific contributions concerning the topology optimisation of an ATM network build on top of the SDH structure. A practical design approach has been developed, which provides assistances to the construction of the ATM network in the SDH infrastructure. The scientific results are summarized in the next thesis.

Thesis 1: Topology optimisation of an ATM network on top of the SDH infrastructure [C1, C2, C3, J1]

The results of this thesis are summarised as follows:

1. By means of mathematical tools, I have exactly formulated the design tasks of topology optimisation for an overlaid ATM network as integer programming problems (Section 2.4), which enables the appropriate choice of planning methods.

2. I have enhanced heuristic algorithms (ADD and MENTOR) accordingly to the specific nature of the planning tasks. I have proposed the combination of these heuristic algorithms to the solution of the design task.

   I have proposed a novel, practical approach for the planning task (Section 2.3). The original design problem has been decomposed into subproblems in such a way, that the code of the optimization algorithms can be efficiently reused.

Further contributions of the dissertation are concerned with QBD and QBD-M processes related topics. The QBD (Quasi Birth Death) process is a two dimensional (phase and level) Markov process on the semi-infinite or the finite state space [7, 18]. It is a generalization of the classical birth and death M/M/1 queues and has a wide applicability in modelling and analysis of telecommunications systems.

In addition, performance analysis tasks sometimes require the extension of QBD processes, leading to the involvement of systems with batch arrivals and batch departures. Such Markov chains are referred to as QBD-M processes, where the letter M stands for multiple changes in

level dimension. There are many systems in which batch arrivals and/or batch departures are interpretable due to their operation features and due to an adequate modelling formulation. Some examples are ATM devices having input and output links of different speeds (ATM concentrators, ATM multiplexers [5]), edge devices transmitting packets of different size at its input and output side [19], processor scheduling scenarios [6], modelling an SVC based IP-over-ATM scenario [16].

There are already some numerical methods for the steady state solution of QBD and QBD-M processes (Chapter 3 and Chapter 5). However, the applicability of each of them is limited due to some certain conditions. This fact has motivated my related research which results in the following theses.

Thesis 2: Development of a fast iterative method for the steady state solution of QBD-M processes [C5, C6, T2]

I have developed a new, efficient iterative method for solving infinite QBD-M processes, where the maximum number of arrivals in batch exceeds the maximum number of simultaneous departures (Section 6.1). This is a generalisation of the method of [19].

I have proven that theoretically this iterative method outperforms some existing ones (the classical matrix geometric [15], Latouche's and Naoumov's methods [11, 14] applied after reblocking) in both time and space complexity.

Thesis 3: Proposal of a generalised invariant subspace based method for the steady state solution of QBD-M processes [C7, J3]

I have shown that by an adequate formalization the theory of generalised invariant subspaces can be applied to determine the steady state solution of QBD-M processes. This is called the generalised invariant subspace based method.

I have given in details the computational algorithm step-by-step and the close form expression for the steady state probabilities of a given QBD-M process (Section 6.2).

Thesis 4: Analytical model construction for some telecommunications systems and experimental evaluation of numerical methods

This thesis is pieced together from three sub theses as follows.

1. **Guideline to the use of numerical methods for QBD processes [C4, J2]**

   In Chapter 4, I have provided a guideline related to the issue: what numerical method should be chosen in a given QBD environment from a set of available methods. Seeking the answer of this issue raises the need for an overall comparative picture related to the performance and capability of the proposed methods. Over the last years, such comparison work is found, for example, in [1, 2, 8, 12, 13, 17].

In my research work, I have compared the performance of five latest numerical methods for QBD processes. Namely, the simple substitution matrix geometric method [15] (MG), the logarithmic reduction method proposed by Latouche et al. [11] (LA), the improved version of LA method, developed by Naoumov et al. [14] (NA), the spectral expansion method [4] (SE) and the invariant subspace based method [3] (IS) are considered. The comparison has been performed for both infinite and finite QBD processes, therefore it is more general than the previous works.
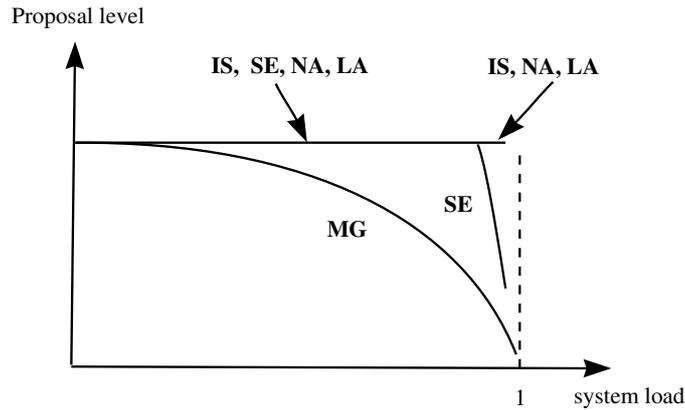

Figure 1: Proposal level of numerical methods for QBD processes based on the output of the developed comparative framework.

The main scientific results are as follows:

- I have developed a framework to judge the performance of the numerical methods in comparison with each other (Section 4.2).
  - I have defined the viable criteria (time complexity and numerical stability) for the assessment of the numerical methods.
  - I have introduced two comparative scenarios for the performance comparison (performance parameter-based criteria and object-based criteria).
- I have proposed the guideline for the choosing policy when applying numerical methods for QBD processes. The most important suggestions are (Section 4.4):
  - I have shown and confirmed that the computational methods exhibit nearly the same efficiency under moderate system loads. For heavy loads, all the methods, except the MG, retain their efficiency regarding to the computation time.
  - I have pointed out that at the verge of system stability the SE method may exhibit instability and produce numerical results differing considerably from those of the other methods. At the same time, the deterioration of the MG method in time-efficiency is observable. The use of LA, NA or IS method in these cases therefore is preferable.

– For the system with a finite buffer, I have shown that the IS method seems slightly superior to other methods in terms of execution time and normally produces numerical results in great coincidence with the results of the SE method.

In summary, Figure 1 informally shows the proposal level of the numerical methods[2], which is based on the output of the developed comparative framework.

2. **Analytical model construction for performance analysis of some telecommunications systems [C6, C8, C9, C10]**

   - I have constructed the model of a node performing multipath routing in MPLS networks. I have pointed out that the QBD-M process is an appropriate tool for analytical performance analysis of this problem (Section 7.1)

   - I have shown that a discrete QBD-M process can be applied to the analysis of an ATM concentrator (Section 7.2).

   - I have modelled a finite queueing system fed by bursty traffic of two priority classes, operated with double-level feedback congestion control by a finite QBD-M process (Chapter 8). I have pointed out the tight relation between this model and the scheduling mechanisms applied in DiffServ network. I have shown that the generalised invariant subspace based method preserves its capability for solving this model (Section 8.3). Moreover, I have derived close form expressions for the important performance parameters of this queueing model (Section 8.5).

3. **Comparative evaluation of numerical methods for QBD-M processes [C6, C7, C9, J3]**

   I have accomplished an in-depth comparison related to the computational performance of the newly developed methods and with some well-known ones (Chapter 7).

   Based on the comparison study, I have proposed the following suggestions regarding the applicability of the novel numerical methods:

   - When the proportion between the upper bounds of arrival batches and departure batches is large enough (greater than 2) and the system load is not too close to the saturation point, the new iterative method is the best one from the aspect of execution time and thus it is most advisable to be used.

   - The generalised invariant subspace based method is the best one regarding to the residual error. Moreover, its computational effort is load-independent and proves faster than the spectral expansion methods and under certain conditions than the new iterative method.

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[2]The proposal level of a given numerical method roughly stands for its goodness and advisability

5   Application of the results and open research directions

The optimisation model and the practical planning approach proposed in Thesis 1 has been applied to a realistic scenario for the introduction of a public ATM network on top of the Hungarian SDH infrastructure.

The planning approach has a great flexibility. It can be used in any another scenario where an ATM network is not realized in the SDH infrastructure (e.g: on the infrastructure of pure fiber optics).

The results and suggestions in Thesis 2, Thesis 3 and Thesis 4, provide valuable assistances to networking engineers to achieve efficient performance evaluations in real-life tasks.

It is also noteworthy that the queueing model examined in Chapter 8 provides a potential way to examine and evaluate scheduling schemes in DiffServ, a scalable architecture for provisioning QoS over IP networks.

The thesis triggers a lot of innovative research directions. One of such challenges is to extend the capability of the iterative method proposed in Section 6.1 to the general cases. Moreover, in addition to the applications presented in Chapter 4, Chapter 7 and Chapter 8, more real-life examples can be worked out to demonstrate the modelling capability of QBD and QBD-M processes. Note that this also enables the extension of the numerical comparison of computational methods to a more comprehensive range.

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