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**Applied Stochastic Modelling in
Telecommunication & Manufacturing**

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Applied Stochastic Modeling in Telecommunication and Manufacturing

The description, analysis and interpretation of the dynamic behaviour is an important and most crucial topic when designing and operating information systems. This was true in the past for classical communication and computer systems. It is even more important for modern and future networks such as ISDN, ATM, mobile networks and distributed systems in general; traffic character and system behaviour change drastically when introducing new and intelligent services.

Some twenty five people from research institutes and universities met to present their research results and to discuss current topics of mutual interest including experimental and theoretical work.

Efficient models have been quite prominent since two sessions and a panel discussion have been devoted to this topic. A large amount of measured data is now available for the new services, and these data seem to call for a new and more sophisticated traffic characterisation. This has led to very lively debates.

We also discussed modelling paradigms. They include classical technique applied to optical networks, combining loss and queueing network models. More recent approaches have also been presented, such as stochastic Petrinets and stochastic process algebras. Naturally, the efficient solution of large Markov chains remains an important issue, since they are the base of most modelling techniques. New and interesting ideas have been presented with this respect.

We also discussed engineering problems in the context of manufacturing systems and modern communication networks, including planning, routing, and generally allocating resources in present as well as future networks. A few presentations were devoted to the extension of matrix-analytic methods for Markov chains. These concern systems with a more general transition probability structure, as well as some speculation about this applicability to spatial processes.

We very much appreciated the hospitality and the stimulating atmosphere at Schloss Dagstuhl. On behalf of all participants we thank the staff of the conference center and would like to say "Auf Wiedersehen".

The Organizers

Ulrich Herzog
Guy Latouche
Vaidyanat Ramaswami
Phuoc Tran-Gia

Proceedings Editor

Manfred Mittler

1 Seminar Program

Monday, 25. September 1995

9.30 - 11.15 SESSION 1

- Hisashi Kobayashi: Loss Network Models and their Application to
All-Optical Networks
- Hans Daduna : Discrete Time Models for Communication
Systems: End-to-End-Delay
- Michel Mandjes : Buffer and Bandwidth Allocation in Single and
Multi-Link ATM networks

11.15 - 12.15 COFFEE and DISCUSSION

12.15 - 14.00 LUNCH

14.00 - 16.15 SESSION 2

- Volker Schmidt : Taylor Expansions for Performance
Characteristics of Stochastic Petri Nets
with Poisson Input
- Christoph Strelen : Approximate product form solutions for
Markov chains
- Christoph Lindemann: Numerical Analysis of Generalized Semi-
Markov Processes
- Ulrich Herzog : Constructing Complex Models Using
Stochastic Process Algebras

16.15 - 17.15 COFFEE and DISCUSSION

Tuesday, 26. September 1995

9.00 - 10.45 SESSION 3

Walter Willinger: The River Nile, the Stock Market, and
High-Speed Networks

Stephan Robert : A Markovian Model for Self-Similar Traffic

Ashok Erramilli : Performance Analysis with Fractal Arrival
Processes

10.45 - 12.15 COFFEE and DISCUSSION

12.15 - 14.00 LUNCH

14.00 - 15.45 SESSION 4

K.R. Krishnan : Long Range Dependence in VBR Video
Streams and ATM Traffic Engineering

Oliver Rose : Simple and Efficient Models for Variable Bit
Rate MPEG Video Traffic

Michael R. Frater Variable Bit Rate MPEG Video Traffic:
Properties and Implications

15.45 - 17.15 COFFEE and DISCUSSION

Wednesday, 27. September 1995

9.00 - 10.45 SESSION 5

Gunter Bolch : Using the Markov Analyser MOSES for Production
Lines with Finite Buffers and Unreliable Machines

Udo Krieger : On numerical methods for the performance
and multiplexers in ATM networks

Manfred Mittelmann : On Cycle Times and Interdeparture Times in
Semiconductor Manufacturing Systems

10.45 - 12.15 COFFEE and DISCUSSION

12.15 - 14.00 LUNCH

14.00 EXCURSION TO TRIER

9.00 - 11.15 SESSION 6

Jean-Yves Le Boudec : Performance Implications for Scalability of
Connection-oriented Networks

Frank Hübner : Performance Evaluation of a Discrete-Time
Queue with Feedback Control

Annie Gravey : Resource allocation in ATM Networks based
on enforceable traffic characteristics

Les Berry : Performance Modelling for Multicast
Communications

11.15 - 12.15 COFFEE and DISCUSSION

12.15 - 14.00 LUNCH

14.00 - 15.45 SESSION 7

Vaidyanat Ramaswami : Spatial Point Patterns of Phase Type
Guy Latouche

Bhaskar Sengupta : Matrix Analytic Methods for Tree
Structures

Jorge Garcia Vidal : A Domain Decomposition Method for
Solving Markov Chain Problems

15.45 - 17.15 COFFEE and DISCUSSION

Friday, 29. September 1995

9.00 - 10.45 SESSION 8

Peter Taylor : Analysis of Level-Dependent
 Quasi-Birth-and-Death Processes

Dieter Baum : On Approximate Solution Methods for
 Multi-Queue Systems with 1-Limited
 Deterministic Service

Konrad Faßnacht Priority Strategies in ATM Networks

10.45 - 12.15 COFFEE and DISCUSSION

12.15 LUNCH / END OF SEMINAR

2 Abstracts

Abstracts are listed in alphabetical order of the invited speaker.

In case of multiple authors, invited speakers are listed first.

On Approximate Solution Methods for Multi-Queue Systems with 1-Limited Deterministic Service

Dieter Baum, Universität Trier, Germany

We consider queueing systems being fed by several distinct arrival streams determining job classes. Their main characteristic consists in the fact, that only one job per stream is admitted at a time into a central queue-server facility, the latter one providing class-independent deterministic service. Models of this kind play an important role in the performance analysis of distributed systems as, for instance, the DQDB network. Their analysis is hard due to the fact, that in general no cyclic behaviour can be exploited, and polling analysis fails. We provide fairly accurate approximations using a closed network interpretation.

Performance Modelling for Multicast Communications

Les Berry, RMIT, Australia

Multirate and multislot circuit-switched traffic models have been proposed by many authors in the context of performance analysis for ATM networks at the call level (COST 242 Report). A simple model is described which characterizes multislot Poisson arrival streams as loss-equivalent single-slot non-Poisson traffic (with peakedness $\rho = 1$). This characterization permits a straightforward modification of the chain flow dimensioning model to extend its application to the case of multislot multicast traffic groups on circuit-switched networks. Initial studies indicate that the traffic transformation may be, for practical purposes, a network insensitive traffic characterization. Some simulation results are given to compare actual and planned end-to-end grades of service on multislot multicast networks dimensioned by the extended chain flow model. Preliminary results are also given to assess the improvement to the network traffic-weighted grade of service when fixed (tree) routing for the multicast groups is replaced by a state dependent route (tree) allocation method which is based on the nearest insertion algorithm.

Modeling Production Lines using the Markov Analyzer MOSES

Gunter Bolch, Universität Erlangen-Nürnberg, Germany

Stefan Greiner, University of Durham, USA

Helmut Herold, Siemens AG Erlangen, Germany

In this contribution the Markov analyzer MOSES (MODelling, Specification and Evaluation System) and the model description language MOSEL (MODELing, Specification and Evaluation Language) – developed at the Institute for Operating Systems at the University of Erlangen-Nuernberg – are described and it is shown how to use these to specify and evaluate production lines with finite buffers, batch processing and unreliable machines.

The core of MOSEL consists of constructs suitable for the specification of the possible states of the system and of RULE constructs which model the state transitions. This specification method is much more compact than other comparable methods and also enables the user to specify large systems.

The Markov analyzer MOSES facilitates the input of MOSEL and subsequently creates the Markovian system of equations automatically. Six different methods are provided for solving this system of equation. MOSES calculates the state probabilities and derives the performance measures from them.

MOSES has been used for the solution of many different problems, among others for analyzing manufacturing systems, computer systems, operating systems, fault tolerant systems and communication systems.

On linear stochastic networks in discrete time

Hans Daduna, Universität Hamburg, Germany

Communication systems using ATM protocols show an inherent generic slotted time scale. The need for an effective performance analysis for such systems renewed the interest in discrete time queueing systems. We discuss the possibility of finding explicit descriptions for the steady state behaviour of some specific stochastic networks. For linear open tandem systems and closed cyclic networks of Bernoulli servers we obtain from the known steady state probabilities explicit expressions for the arrival probabilities of customers in equilibrium. Although the arrival probabilities are of product form structure, a PASTA analogue does not hold.

Starting from this arrival distributions we compute the joint distribution of a customer's sojourn times at the nodes during one cycle in the closed system, which yields as a byproduct the cycle time distribution in equilibrium.

The result is then used to compute the joint distribution of a customer's sojourn time at the nodes when traversing an open tandem in steady-state, and its end-to-end-delay distribution.

All results yield explicitly given probabilities, which provide us with delay time quantiles as a performance measure for the networks.

Performance Analysis With Fractal Arrival Processes

Ashok Erramilli, Bellcore, USA

Recent measurement studies in Bellcore and elsewhere have convincingly established the presence of statistical self-similarity in high-speed network traffic. This has motivated new areas of research in mathematical modeling, queueing analysis, network design and control. In particular, the analysis of queues driven by arrival processes exhibiting complex fractal characteristics is the focus of intense current research. In this presentation, we will review the broad range of modeling techniques that are being applied to this problem, and discuss one particular approach, based on deterministic chaotic maps, in more detail. All the analysis approaches we review predict queue length distributions that decay more slowly than the exponential decay observed with short-range dependent arrival processes. This prediction is also supported by simulations with actual traffic traces. We conclude with practical engineering impacts of such heavy-tailed queueing behavior, and relate these to early experiences with operating ATM networks.

Priority Strategies in ATM networks

Konrad Faßnacht, Universität Augsburg, Germany

ATM-cells may be divided into two classes: Low Loss (LL)-cells with strong requirements to the loss probability and Low Delay (LD)-cells with strong requirements to the cell delay in buffers. The loss probability for LL-cells should not exceed $10E-10$, whereas the loss probability for LD-cells should stay below $10E-6$. The demand for low delay of the LD-cells does not allow the design of buffers of any length.

To meet the requirements for the loss probabilities of both type of cells in an M/M/1/n-model with fixed arrival rates for LL- and LD-cells, three different kinds of queueing disciplines are studied. In an ordinary FCFS-buffer the loss probabilities are equal for both type of cells. The calculation of the loss probabilities is based on the fluid balance equations in birth/death-processes. The partial buffer sharing mechanism separates the buffer into two parts. Up to a separating boundary k both types of cells may enter the buffer. Above k only LL-cells are accepted in the buffer, LD-cells are lost even if the buffer is still not full. Again the fluid balance equations are used to calculate the loss probabilities. The push out mechanism works as an FCFS buffer as long as the buffer is not full. If the buffer is full a LD-cell is lost at once. An arriving LL-cell starts to scan the buffer for an LD-cell, beginning at the end n of the buffer. If it finds a LD-cell it pushes this out and occupies its place in the buffer. The scanning procedure is stopped at a sharing boundary m between 0 and n . If there is no LD-cell in the buffer between n and m the LL-cell is lost. The calculation of the loss probabilities requires some combinatorial methods. The push out mechanism is much more efficient than the partial buffer sharing mechanism, but it is almost impossible to implement this discipline efficiently.

Further work will consider different states of the arrival rates Therefore the arrival process will be modelled for example as a MMPP or as a MAP. The separating boundary k , the sharing boundary m and the bufferlength n will be calculated depending on the parameters of the arrival process in order to gain a dynamic or adaptive mechanism to control the buffer discipline. An important feature of this work will be the real-time estimation of the parameters. Besides this the delay and the delay jitter for the models will be taken into account.

Variable Bit Rate MPEG Video Traffic: Properties and Implications

Michael R. Frater, University of New South Wales, Australia

It is widely believed that video services will provide an important source of traffic for future telecommunications networks, such as the Broadband-ISDN. From the point of view of these video services, there are advantages in being able to provide delivery at a variable, rather than constant, bit rate. This issue has received much attention recently in the literature. In this talk, we will describe briefly the general characteristics of variable bit rate video traffic, and present new results obtained from measurements made on real variable bit rate video traffic. The results described relate to

1. Deterministic properties,
2. Markovian properties,
3. Long range dependence,
4. Stationarity.

Finally, some ideas on the implications of these results for network performance and control will be presented.

A Domain Decomposition Method for Solving Markov Chain Problems

Jorge Garcia, J. M. Cela, and R. Nunez
Universidad Politecnica de Cataluna, Spain

In this paper we address the use of a parallel iterative method using the Schur complement matrix (equivalent to the Stochastic complementation technique) to find the steady state solution of a certain class of Markov chains with a large number of states. We compare the proposed scheme with the classical incomplete factorization preconditioned method. From the numerical results, we conclude that the proposed technique will lead to an improvement of the convergence for certain Markov chains arising, for instance, in the modelling of communication systems.

The implementation aspects of this algorithm in parallel machines with a message passing programming paradigm are also studied.

Resource allocation in ATM Networks based on enforceable traffic characteristics

Annie Gravey, France Télécom, France
J. Mignault, Ecole Polytechnique de Montréal, Canada
Karine Sevilla, France Télécom, France

Resource allocation is one of the key problems to be solved in ATM Networks. Models are needed for evaluating the resources that a network should allocate to a source in order to ensure a given level of delivered Quality of Service.

Many known models, on which CAC methodologies are designed, assume that statistical characteristics of the sources are known (e.g. mean cell rate, burstiness) and base the resource allocation strategy on

these statistical characteristics. However, statistical characteristics are usually not enforceable, and therefore a network cannot control that user traffic conforms to these statistical characteristics. It may therefore not be possible to ensure that a given level of QoS is delivered to connections.

It is proposed here to allocate resources on the basis of the so called “Worst Case Traffics” (WCTs) that are compatible with the traffic characteristics (e.g. Peak Cell Rate and CDV tolerance) that have been negotiated at call establishment and of the characteristics of the ATM Network Equipments (NEs).

Currently, only open-loop control of traffic characteristics is implemented in NEs. It is thus only possible to offer the Deterministic Bit Rate (DBR) and the Statistical Bit Rate (SBR) transfer capabilities. Furthermore, depending on the characteristics of the NEs (segregation of DBR traffic, size of buffers ...), resource allocation policy may vary.

Typical examples are considered, and simple models are identified, that allow to identify, for several cases, the relevant traffic characteristic. Emphasis is put on the relationship between QoS guarantees and enforceable traffic characteristics.

Constructing Complex Models Using Stochastic Process Algebras.

Ulrich Herzog, Universität Erlangen-Nürnberg, Germany

Designing parallel and distributed systems there are two major aspects: the functional description and analysis as well as the temporal description and analysis. Unfortunately, however, both aspects are usually separated from each other. And it is not unusual for a system to be fully designed and functionally tested before an attempt is made to determine its performance or dependability characteristics. Redesign of both hardware and software is usually the consequence being costly and causing late system delivery.

The need for an integral description and treatment examples are Stochastic Petri Nets and Stochastic Graph Models.

We introduce Stochastic Process Algebras as a novel approach for the structured design and analysis of both the functional behaviour and performability (i.e. performance and dependability) characteristics of parallel and distributed systems. This is achieved by integrating stochastic modelling and analysis into the powerful and well investigated formal description techniques of process algebras.

After advocating the use of Stochastic Process Algebras as a modelling technique, we recapitulate the foundations of classical process algebras (syntax, semantics, equivalences and equational laws) allowing one to construct systems systematically from smaller ones. We present extensions taking into account the requirements of performability analysis.

We briefly survey the state-of-the-art of Stochastic Process Algebras (a complete theory is available when the timing behavior is described by exponential and immediate transitions; a prototype-tool is available allowing to investigate functional, temporal as well as mixed properties; several examples from communications, robotics, multiprocessor modelling show the feasibility of the approach). We also discuss the major research directions (theoretical foundation, efficient evaluation techniques and large applications).

Performance Analysis of a Queue with Multi-Level Hysteresis Control and Feedback Delay

Frank Hübner, Bellcore, USA

We consider a finite queue in discrete-time domain where arrivals are described by GI inter-arrival time distributions. The arrival process is controlled by feedback information that forces the arrival process intensity to decrease once the queue length exceeds a certain threshold and allows again for a higher intensity when the queue length decreases below another threshold. This control is known as hysteresis control and we consider here the case that we have multiple levels of this control and that the feedback information is delayed between the queue and the arrival process control.

By decomposing the entire state space into state spaces describing the behavior of the queue when the arrival process is in one specific level, we are able to derive the state probability distributions using a discrete-time iteration technique. In case of no delay between the queue and the arrival process control we derive an exact solution for the loss probability and the throughput of the system. Since delay between the queue and the arrival process control leads to a very complex system behavior (where the control may not have the correct view of the actual congestion level at the queue), we derive an approximate solution for the case of non-zero delay.

Numerical results not only indicate the excellent accuracy of the analytical results (by comparison with simulation results), but also demonstrate that using two arrival process levels gives the best performance in terms of low loss probability/high throughput trade-off. We also discuss which parameters influence the performance of the control fundamentally and derive guidelines for their choices.

Loss Network Models and Applications to All-Optical Networks (AONs)

Hisashi Kobayashi, Princeton University, USA

Recently, there has been a renewed interest in generalization of the loss models originally studied by Erlang and Engset in the context of telephone exchange. Loss networks provide models for studying the blocking behavior of connection-oriented services in circuit-switched communication networks [1], ATM networks, etc. New applications of loss networks include broadband optical networks and wireless networks.

In this talk, we first present relations between a class of loss networks and queueing networks, whose stationary distributions have a product form [2,3]. We formalize several generalizations of the classical loss models studied by Erlang and Engset. Under multiclass service, with multiple server acquisition, the generalized loss stations retain the properties of insensitivity to holding time distributions and inter-generation time distributions for the finite source model. By considering infinite (i.e., Poisson) and finite source models, we introduce the notions of open, closed and mixed loss networks, in analogy to the corresponding concepts for queueing networks. We obtain expressions for time and call congestion for open and closed routes. Taking approach similar to [4], we obtain generating functions which lead to computational expressions for several quantities of interest [3]

We then discuss an application of loss network model to the performance analysis of all-optical networks (AON). AONs are emerging as the next generation broadband networks for both wide-area and local-area networks. We analyze the call blocking performance of a class of wavelength grating routers (WGRs), which are currently being developed as the basis of an AON architecture [5]. Our modeling approach based on loss networks takes into account the widely varying bandwidth requirements of

calls to be supported on the AON. We obtain expressions for call blocking probability for various configurations of WGRs under general traffic [6,7].

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On numerical methods for the performance evaluation of buffers and multiplexers in ATM networks

Udo R. Krieger, Deutsche Telekom AG, Germany
Valeri Naoumov, Russian Academy of Science, Russia
Dietmar Wagner, Technische Hochschule Darmstadt, Germany

First we study output buffers in an ATM switching fabric with channel grouping. As generic model a generalization of Erlang's delay-loss system $\overrightarrow{\text{MAP}}/\text{PH}/n/m$ with a superposition of independent MAP arrival streams and phase-type distributed service times is stated. The generator matrix of the underlying continuous-time Markov chain is derived. The steady-state distribution of this finite QBD process with two boundaries has a specific matrix-geometric form. The latter is calculated by a new cyclic reduction method. Then the performance characteristics of the model are determined using the steady-state vector.

In the second part of the talk, a new recursive algorithm is stated to calculate the call-congestion rates of a related ATM multiplexer model $\overrightarrow{\text{MAP}}/\text{PH}/1/m$ as function of the buffer size. It is derived from Naoumov's new solution method for block tridiagonal matrices satisfying an additional block lumpability condition.

Long Range Dependence in VBR Video Streams and ATM Traffic Engineering

K. R. Krishnan and G. Meempat, Bellcore, USA

It was shown in a recent study that traffic rates in high-speed data networks exhibit 'long-range dependence' in their correlation, characterized by the so-called Hurst parameter H assuming values in the range $0.5; H; 1$. This corresponds to correlation that has a smaller asymptotic rate of decay than in Markovian processes, for which $H=0.5$. Simulations suggest that link-engineering based on Markovian traffic models could, in some situations, underestimate the bandwidth requirements of the actual traffic. However, in another study, a Markovian traffic model has been used with success to determine bandwidth requirements for Variable-Bit-Rate video sources, which have $H; 0.5$.

We report here the results of an investigation undertaken to bridge the gap in our understanding of the results of these two studies, and to analyze the effect of the Hurst parameter on link-engineering for ATM traffic. Our investigation has shown that a curious 'scaling' property of streams with long-range dependence helps to bridge the gap, by accounting for the results of both studies. The analysis suggests that a high value of H is not, in itself, a reason to suppose that Markovian traffic models will lead to under-engineering of bandwidth on ATM links.

Numerical Analysis of Generalized Semi-Markov Processes

Christoph Lindemann, GMD-FIRST, Germany
Gerald Shedler, IBM Almaden Research Center, USA

Numerical methods for discrete-event stochastic systems are needed in connection with performance and dependability models of computer and communication systems. We consider finite-state generalized semi-Markov processes with exponential and deterministic clock-setting distributions and provide an efficient numerical method for computing limiting distributions of such processes. The method rests

on observation, at equidistant time points, of the continuous time Markov process that records the state of the generalized semi-Markov process and clock readings associated with deterministic events and analysis of the resulting general state space Markov chain. The numerical method is valid not only when at most one deterministic event may be active at any time point, but also when deterministic events may be concurrently active. The techniques of this paper are applicable to networks of queues, deterministic and stochastic Petri nets, stochastic process algebras, and other discrete-event stochastic systems with an underlying stochastic process that can be represented as a generalized semi-Markov process.

Pre-Computed Routing for ATM

Jean-Yves Le Boudec, Swiss Federal Institute of Technology, Switzerland

Routing is an essential element of ATM network control. Route computation contributes significantly to connection setup latency. In order to increase the performance of ATM networks, and especially their connection handling capacity, we explore the possibility of computing routes in advance. We present an algorithm (MOP) for computing best routes without a priori knowledge of connection characteristics. We explore such issues as equivalence with on demand computing, run time performance, and applicability to support of SCR connections.

A new approach to buffer and bandwidth allocation in single- and multi-link ATM systems

Michel Mandjes, Vrije Universiteit Amsterdam, the Netherlands

Hans van den Berg, KPN Research, the Netherlands

This paper studies the optimal allocation of bandwidth and buffer space in single and multi-link ATM systems, subject to loss and delay constraints. First, a useful approximate relation between buffer size and required bandwidth is derived for the single-link model with Markov modulated fluid input. This relation is shown to be asymptotically exact, for the case that the buffer size becomes large. Second, buffer and bandwidth allocation for multi-link models, e.g. tandem and intree networks, is studied. For that purpose we use a simulation technique (described in a previous paper), by which small loss ratios can be estimated quickly exploiting importance sampling. Using this technique a large number of scenarios can be evaluated in a reasonable amount of time. Particularly, it is found from the numerical results that the asymptotic relation for the single-link case is also useful for the determination of the required bandwidth for traffic streams in multi-link systems. In conjunction with some heuristic ideas, we propose manageable and reasonably accurate guidelines for resource allocation. In particular, under certain delay and loss constraints, it is shown how to optimally allocate buffer space and bandwidth in tandem and intree networks.

On Cycle Times and Interdeparture Times in Semiconductor Manufacturing

Manfred Mittler, Notker Gerlich, and Alexander K. Schömig
Universität Würzburg, Germany

In this paper we investigate the distribution and the long-range dependence of cycle times and interdeparture times in two semiconductor manufacturing systems. The results were obtained by means of simulation using original work floor level data of semiconductor fabrication facilities. The findings presented here show that for those semiconductor facilities under consideration the normal distribution is a very good approximation of the cycle time distribution. This relation holds for several queuing disciplines and varying service time distributions. Furthermore, we show that in some cases the distribution of interdeparture times can be approximated by the exponential distribution. We discuss the few cases where the exponential distribution does not fit at all. Finally, we address the long-range behavior and the degree of persistence of both cycle times and interdeparture times.

Spatial Point Patterns of Phase Type

Vaidyanat Ramaswami, Bellcore, USA
Guy Latouche, Université Libre de Bruxelles, Belgium

Motivated by telecom applications like Personal Communication Services, we develop a set of spatial point pattern models that are natural multi-dimensional generalizations of the Markovian Point Processes (MAP) of Neuts. Like their linear counterparts, these offer the versatility to model a wide variety of spatial dependencies and burstiness characteristics while maintaining computational tractability. A construction of such processes is given that is easy to simulate, and examples are provided to illustrate how special cases may be defined to incorporate qualitative characteristics of interest to application areas. These make the processes considered here a viable and attractive alternative to commonly used Poisson models that are limited by the independence of counts across non-overlapping spatial subsets.

A Markovian Model for Self-Similar Traffic

Stephan Robert, Swiss Federal Institute of Technology, Switzerland

Recent papers have pointed out that data traffic exhibits self-similarity, but self-similarity is observed only on a finite timescale. In order to account for that, we introduce the concept of pseudo long-range dependencies. In this paper, we describe a Modulated Markov process producing self-similarity on a finite timescale; the process is quite easy to manipulate and depends only on three parameters (two real numbers and one integer). An advantage of using it is that it is possible to re-use the well-known analytical queueing theory techniques developed in the past in order to evaluate network performance. A quantitative method based on the *decomposability* theory of Courtois is given to evaluate the domain of validity where the process exhibits pseudo long-range dependencies. The tests performed to validate the model are the following: Hurst parameter (by the variances method) and the so-called 'visual' test. A method of fitting the model to measured data is also given. Finally, we describe a simulator generating traffic based on the Markov Modulated process.

Simple and Efficient Models for Variable Bit Rate MPEG Video Traffic

Oliver Rose, Universität Würzburg, Germany

For the performance analysis of ATM networks carrying Variable Bit Rate (VBR) MPEG video sequences there is a need for appropriate video traffic models. In this paper, we discuss Markov chain models for this specific type of traffic with respect to several statistical properties and their ability to predict cell losses at buffers of ATM multiplexers. We intentionally selected a simple model class to check for its appropriateness to model a complex traffic type. The results of this paper show that Markov chain models can be used efficiently for MPEG video traffic under the following conditions. The Group of Pictures (GOP) generation process should be modeled rather than the frame process. If the performance measures depend on the correlation properties of the video traffic the scene process should also be considered in the course of the model development.

Taylor expansions for Poisson driven $(\max, +)$ -linear systems

Volker Schmidt, Universität Ulm, Germany
Francois Baccelli, INRIA Sophia Antipolis, France

We give a Taylor expansion for the mean value of the canonical stationary state variables of open $(\max, +)$ -linear stochastic discrete event systems with Poisson input process. The coefficients of all orders are computed explicitly. The method for proving these results is based on two ingredients: a) the $(\max, +)$ -linear representation of the stationary state variables as functionals of the input point process; b) the Taylor expansion representation of functionals of marked point processes, and in particular of Poisson point processes. However, no Markov-type assumptions are needed. $(\max, +)$ -linear systems allow one to represent stochastic Petri nets belonging to the class of event graphs. This class contains various instances of queueing networks like acyclic or cyclic fork-join queueing networks, finite or infinite capacity tandem queueing networks with various types of blocking (manufacturing and communication), synchronized queueing networks etc. It also contains several basic manufacturing models such as Kanban networks, Job-Shop systems etc.

Matrix Product-Form Solutions for Markov Chains and a LCFS Queue

Bhaskar Sengupta, NEC, USA
Raymond W. Yeung, Chinese University of Hong Kong,
Hong Kong

We consider a bivariate Markov chain in which one of the variables can take values in a countable set, which is arranged in the form of a tree. The other variable takes values from a finite set. Each node of the tree can branch out into d other nodes. The steady state solution of this Markov chain has a matrix product-form, which can be expressed as a function of d matrices $R_1, \dots, R_d$. We then use this to solve a multi-class LCFS queue, in which the service times have PH-distributions and arrivals are according to the Markov modulated Poisson process. In this discipline, when a customer's service is preempted in phase j (due to a new arrival), the resumption of service at a later time could take place in a phase which depends on j .

Approximate product form solutions for Markov chains

Johann Christoph Strelen, Universität Bonn, Germany

An aggregation technique for finite state, discrete time Markov chains is proposed. Time dependent and steady state solutions are in product form which can be calculated iteratively. This iteration is equivalent to disaggregating state probabilities, multiplying with transition probabilities, and aggregating state probabilities - we call it "DA iteration". Markov chains with many states can be treated.

In this way one obtains accurate approximations, and moreover, the accuracy can be controlled: The more aggregates are considered, the better the approximation can be, if the aggregates are chosen suitably.

Practical experience is encouraging: We solved many polling, fork-join, stochastic Petri net, and blocking models successfully. The obtained accuracy compares favourably with other approximate methods and with exact solutions.

General properties of DA iteration are hard to state. We report from unsolved and some solved problems.

DA iteration also can be applied to continuous time Markov chains by analyzing a suited Markov chain with the same steady state probabilities and using the randomization technique.

Analysis of Level-Dependent Quasi-Birth-and-Death Processes

Peter Taylor and Les Bright
University of Adelaide, Australia

The spatially-homogeneous quasi-birth-and-death process (QBD) has proved to be a very successful tool for analysing many real-world systems. When the assumption of spatial homogeneity is discarded, we obtain the class of level-dependent QBDs. This class promises also to be a potent modelling tool.

Instead of the usual matrix quadratic equations $G = A_2 + A_1 G + A_0 G^2$ and $R = A_0 + R A_1 + R^2 A_2$, in level-dependent QBDs it is desired to solve the non-linear systems of equations $G_k = A_2^{(k)} + A_1^{(k)} G_k + A_0^{(k)} G_{k+1} G_k$ and $R_k = A_0^{(k)} + R_k A_1^{(k+1)} + R_k R_{k+1} A_2^{(k+2)}$ respectively. In this talk, I will show how this can be done by using a level-dependent modification of Latouche and Ramaswami's logarithmic-reduction algorithm. In addition to the general case, I will examine a number of special cases in which the algorithm takes on a particular simple form. Some numerical examples will be given.

The River Nile, the Stock Market, and High-Speed Networks

Walter Willinger, Bellcore, USA

From a data analysis and mathematical modeling point of view, there exist many parallels between studying bursty phenomena such as the water flows of rivers (e.g., Nile, Rhine), the ups and downs of stock prices (e.g., IBM, Daimler-Benz), and the nature of traffic in today's high-speed communications networks (e.g., LANs, WANs, ATM networks).

In this talk, I will discuss some of these similarities and will illustrate how they give rise to methods for effectively analyzing and modeling Giga/Tera-bytes of high-quality, high-time resolution traffic measurements from tomorrow's high-speed networks.

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