Preface

This booklet collects the abstracts of the talks presented at the *Second Madrid Conference on Queueing Theory (MCQT'06)*, Department of Statistics and Operations Research, Faculty of Informatics, Complutense University of Madrid, Spain, July 3-7, 2006. The Madrid Conference on Queueing Theory aims to be a meeting place where scientists and technicians in the field could find a discussion forum to promote research, encourage interaction and exchange of ideas. The conference is open to all trends in Queueing Theory including development of the theory, methodology, computational advances and applications.

This second edition is gathering together approximately 91 participants from 23 countries. The Opening Lecture of the conference will be given by Onno Boxma (Eindhoven University of Technology and Eurandom). Eleven Invited Speakers will introduce and show the border lines of a variety of queueing topics. In addition, 63 submissions have been selected as Contributed Talks.

A selection of the best papers presented at the conference will be published in special volumes of the journals *Annals of Operations Research (AOR)* and *Queueing Systems (QUESTA)*. The papers will be refereed following the usual standards of all major international journals. AOR will devote one volume to high quality papers on the topic "Computational Methods and Applications in Queueing Theory" whereas QUESTA will devote two issues to papers which make a significant contribution to the topic "Theoretical and Methodological Advances in Queueing Theory".

The *6th International Workshop on Retrial Queues*, July 8-10, Miraflores de la Sierra, is organized as a satellite meeting of the MCQT'06. The conference chairman is Antonio Gómez-Corral. A selection of the best contributions will be published in the special issue "Advances in Retrial Queues" of the *European Journal of Operational Research*.

I would like to express my sincere gratitude to all participants. Thanks are also due to the institutions which supported the conference: Ministerio de Educación y Ciencia, Universidad Complutense de Madrid and the Applied Probability Society of INFORMS.

Jesús Artalejo

Contents

Organization

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A. Rodrigo

General Information

Date

July 3 (Monday) – July 7 (Friday), 2006

Venue

Faculty of Informatics
Complutense University of Madrid

Organized by

Complutense University of Madrid

Supported by

Ministerio de Educación y Ciencia (MEC)
Complutense University of Madrid (UCM)
Applied Probability Society of INFORMS

Internet site

http://www.mat.ucm.es/~mcqt/confe06/conf06.html

Publication

A selection of the papers presented at the Conference will appear in special volumes of the journals *Annals of Operations Research* and *Queueing Systems*.

Conference Information

Social Program

All participants are invited to attend the following events:

Opening Ceremony

- Date & Time: July 3 (Monday), 2006, 14:15-14:30
- Place: "Salón de Actos"

Royal Palace Trip

All participants and their companions are invited to attend the "Royal Palace Trip" on the afternoon of Thursday 6 July 2006. The trip includes a visit to the Royal Palace followed by a sightseeing of the "*Madrid de los Austrias*".

- Date & Time: July 6 (Thursday) 2006, 14:00-18:15
- Place: Buses will be waiting for the participants at the main entrance of the Faculty of Informatics. The departure time is 14:00. Your strict punctuality is kindly requested.

Conference Dinner

There will be a conference dinner on the fourth day of the conference. A personal card of invitation for each registered person is included among the conference documentation.

- Date & Time: July 6 (Thursday) 2006, 21:15-23:00
- Place: Restaurant "*La Casa de Valencia*"

Where to Have Lunch

Participants will receive coupons for having lunch at the self-service restaurant of the Faculty of Informatics. An extra free coupon for the lunch of the accompanying persons on Thursday 6 is also provided.

Internet Room

You can check your e-mail at the Laboratory 2, which is located on the Floor 2. The daily timetable is as follows:

- From Tuesday 4 to Thursday 6, 12:50-13:50
- Friday 7, 14:30-15:30

The password for the MCQT'06 participants is ep_congreso1.

The Guide Map of the Conference Venue

Ground Floor B

1. Registration (Monday, July 3)
2. Salón de Actos
3. Cafeteria and Self-service Restaurant

First Floor

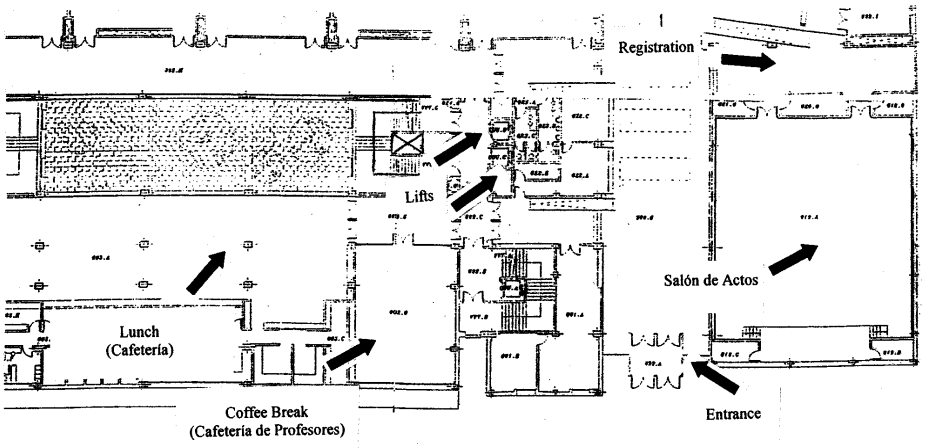
1. Room 14 (Registration, Tuesday, July 4, and Wednesday, July 5)
2. Rooms 15 and 16

Second Floor

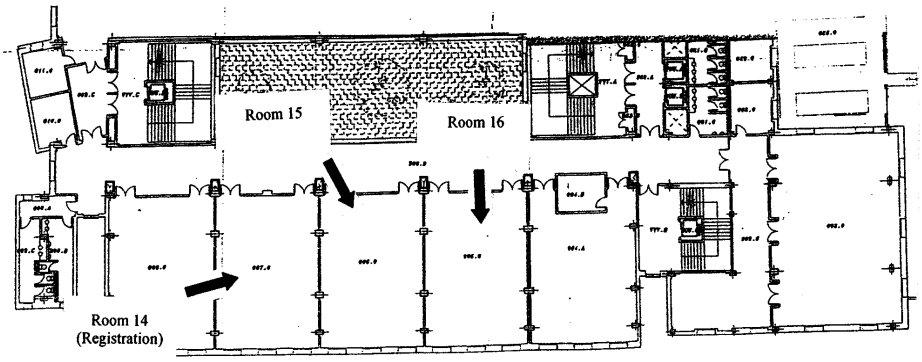
1. Laboratory 2

Important Places

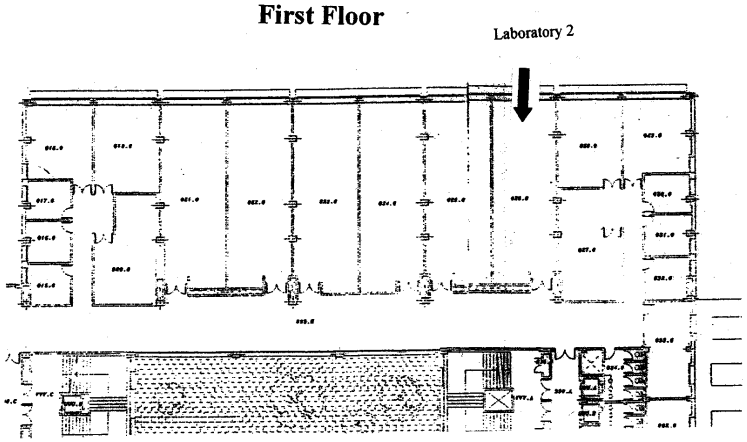
1. Registration Desk: Main Hall (Monday, July 3, Floor B) and Room 14 (Tuesday, July 4, and Wednesday, July 5, First Floor)
2. Opening and Plenary Sessions: Salón de Actos (Floor B)
3. Parallel Sessions: Rooms 15 and 16 (First Floor)
4. Coffee Breaks: Cafetería de Personal (Floor B)
5. Lunch: Cafetería (Self-service Restaurant, Floor B)
6. Internet Room: Laboratory 2 (Second Floor)



Floor 0



First Floor



Second Floor

Program Schedule

July 3, 12:00 hours to 18:25 hours
Main Hall: Registration
Room "Salón de Actos": Opening Ceremony and Opening Session
Room 15: Session Mo-R15
Room 16: Session Mo-R16

12:00 – 14:00 Registration

14:15 – 14:30 Opening Ceremony

Opening Session – Chair: I.J.B.F. Adan

14:30 – 15:20 Opening Lecture: **Sojourn times in queueing networks**
Author: *O.J. Boxma* (EURANDOM and Eindhoven University of Technology, The Netherlands)

15:20 – 16:10 Invited Talk: **Queues with advance reservations**
Authors: *R.J. Maillardet* and *P.G. Taylor* (University of Melbourne, Australia)

16:15 – 16:45 Coffee Break

Session Mo-R15 – Chair: F. Machihara

16:45 – 17:10 Contributed Talk: A recursion formula for a finite discrete-time queue and a related spectral method
Author: *S. Nishimura*

17:10 – 17:35 Contributed Talk: Queueing analysis of a degenerate buffer with general inter-arrival and service times
Authors: *W. Rogiest*, *K. Laevens*, *J. Walraevens* and *H. Bruneel*

17:35 – 18:00 Contributed Talk: Performance analysis of a discrete-time queue with multiple reservations
Authors: *S. De Vuyst*, *S. Wittevrongel* and *H. Bruneel*

18:00 – 18:25 Contributed Talk: Waiting time distribution in a $Geo/G/1$ retrial queue
Author: *S.I. Rabia*

Session Mo-R16 – Chair: A. Burnetas

16:45 – 17:10 Contributed Talk: New results for the finite dam models of the $M/G/1$ and the $G/M/1$ queues
Authors: *D. Perry*, *W. Stadje* and *S. Zacks*

17:10 – 17:35 Contributed Talk: Transient and asymptotic periodic solution to the quasi-birth-death process with time-inhomogeneous transition rates
Author: *B. Margolius*

17:35 – 18:00 Contributed Talk: Bayesian analysis of a queueing system with a long-tailed arrival process
Authors: *P. Ramírez*, *R.E. Lillo* and *M.P. Wiper*

18:00 – 18:25 Contributed Talk: Priority queueing systems with switchover (orientation) time: Results and open problems
Author: *G.K. Mishkoy*

July 4, 9:00 hours to 17:45 hours
Room "Salón de Actos": Session Tu-SA
Room 14: Registration
Room 15: Sessions Tu-R15a, Tu-R15b, Tu-R15c
Room 16: Sessions Tu-R16a, Tu-R16b, Tu-R16c

9:00 – 9:30 Registration

Session Tu-SA – Chair: T. Takine

9:30 – 10:20 Invited Talk: **Discrete-time $BMAP/PH/1$-type queues analyzed as QBDs**
Authors: *G. Latouche* (Université Libre de Bruxelles, Belgium), *M.A. Remiche* and *G. Renard*

Session Tu-R15a – Chair: R.D. van der Mei

10:30 – 10:55 Contributed Talk: Location-allocation of service units on a congested network
Authors: *R. Aboolian*, *O. Berman* and *Z. Drezner*

10:55 – 11:20 Contributed Talk: A fixed point iteration scheme for closed queueing networks with phase-type service distributions and arbitrary buffer sizes
Authors: T. Dayar and A. Meriç

11:20 – 11:45 Contributed Talk: Zero-automatic networks
Authors: *T-H. Dao-Thi* and *J. Mairesse*

11:45 – 12:10 Contributed Talk: Randomized approximation scheme and perfect sampler for closed Jackson networks
Authors: *S. Kijima* and *T. Matsui*

Session Tu-R16a – Chair: G. Koole

10:30 – 10:55 Contributed Talk: Performance analysis of IEEE 802.11 DCF and IEEE 802.11e EDCA in non-saturation condition
Authors: *T.O. Kim*, *K.J. Kim* and *B.D. Choi*

10:55 – 11:20 Contributed Talk: On performance characteristics for queueing system with heterogeneous servers
Authors: *V. Rykov* and *D. Efrosinin*

11:20 – 11:45 Contributed Talk: Dynamic thread assignment in layered networks
Authors: *W. van der Weij*, *S. Bhulai* and *R.D. van der Mei*

11:45 – 12:10 Contributed Talk: Optimal admission control in tandem queues with blocking
Authors: *A. Burnetas* and *W. Millhiser*

12:20 – 13:50 Lunch Time

Session Tu-R15b – Chair: A. Gómez-Corral

13:50 – 14:40 Invited Talk: **Multiclass Markovian fluid queues**
Authors: *H. Masuyama* and *T. Takine* (Osaka University, Japan)

14:40 – 15:05 Contributed Talk: Probability of traffic loss in a backbone network with statistical multiplexing, QoS differentiation and unicast/multicast routing
Author: *G.L. Choudhury*

15:05 – 15:30 Contributed Talk: Third generation mobile customer network
Author: *F. Machihara*

15:30 – 15:55 Contributed Talk: Delay jitter analysis
Authors: *B. Oklander* and *M. Sidi*

Session Tu-R16b – Chair: G. Weiss

13:50 – 14:40 Invited Talk: **Service level and monotonicity in call center queueing models**
Author: *G. Koole* (Vrije University of Amsterdam, The Netherlands)

14:40 – 15:05 Contributed Talk: Staffing to maximize profit for call centers with alternate service level agreements
Authors: *O. Baron* and *J. Milner*

15:05 – 15:30 Contributed Talk: Stability analysis of regenerative queues
Author: *E. Morozov*

15:30 – 15:55 Contributed Talk: Foster's theorem of critical branching processes: Unifying results for polling models in heavy traffic
Author: *R.D. van der Mei*

16:00 – 16:30 Coffee Break

Session Tu-R15c – Chair: D. Perry

16:30 – 16:55 Contributed Talk: Merging and splitting autocorrelated arrival processes and impact on queueing performance
Authors: *B. Balcioglu*, *D. Jagerman* and *T. Altiok*

16:55 – 17:20 Contributed Talk: A queueing system with discrete autoregressive arrivals of order p
Authors: *B. Kim* and *K. Sohraby*

17:20 – 17:45 Contributed Talk: On the analysis of batch arrival $GI/M/./.$ queues with state dependent service rates and a class of customer acceptance policies
Authors: *F. Ferreira* and *A. Pacheco*

Session Tu-R16c – Chair: O. Berman

16:30 – 16:55 Contributed Talk: SQF: A slowdown queueing fairness measure
Authors: *B. Avi-Itzhak*, *H. Levy* and *E. Brosh*

16:55 – 17:20 Contributed Talk: Job transfers between queues with unreliable servers
Authors: *S.P. Martin* and *I. Mitrani*

17:20 – 17:45 Contributed Talk: On queues with service and interarrival times depending on waiting times
Authors: *O.J. Boxma* and *M. Vlasiou*

July 5, 9:00 hours to 17:45 hours
Room "Salón de Actos": Session We-SA
Room 14: Registration
Room 15: Sessions We-R15a, We-R15b, We-R15c
Room 16: Sessions We-R16a, We-R16b, We-R16c

9:00 – 9:30 Registration

Session We-SA – Chair: P.G. Taylor

9:30 – 10:20 Invited Talk: **Resource allocation in multi-site stochastic service systems**
Author: *X. Chao* (North Carolina State University, USA)

Session We-R15a – Chair: A. Pacheco

10:30 – 10:55 Contributed Talk: Sojourn times in a perturbed $M/M/1/-PS$ queue
Authors: *N. Antunes*, *C. Nunes* and *A. Pacheco*

10:55 – 11:20 Contributed Talk: The $MAP/M/(M/G)/1$ processor-sharing queue with server breakdowns and repairs
Authors: *J. Wang* and *Q. Li*

11:20 – 11:45 Contributed Talk: Tail behaviour of conditional sojourn times in processor-sharing queues
Authors: *R. Egorova* and *B. Zwart*

11:45 – 12:10 Contributed Talk: A fluid approximation for a processor sharing queue with Markov-modulated input
Author: *B. Zwart*

Session We-R16a – Chair: H. Bruneel

10:30 – 10:55 Contributed Talk: A priority scheduling discipline with controlled priority jumps
Authors: *T. Maertens*, *J. Walraevens* and *H. Bruneel*

10:55 – 11:20 Contributed Talk: Discrete-time queueing systems with multiple priority classes and non-preemptive priority scheduling
Authors: *B. Vinck* and *H. Bruneel*

11:20 – 11:45 Contributed Talk: Sojourn time approximations in small homogeneous packet switches
Authors: *P. Beekhuizen*, *D. Denteneer* and *I.J.B.F. Adan*

11:45 – 12:10 Contributed Talk: A discrete-time queueing model in a random environment
Author: *R. Nobel*

12:20 – 13:50 Lunch Time

Session We-R15b – Chair: X. Chao

13:50 – 14:40 Invited Talk: **A simple Markovian re-entrant line with infinite supply of work under the LBFS policy**
Authors: *I.J.B.F. Adan* (Eindhoven University of Technology, The Netherlands) and *G. Weiss*

14:40 – 15:05 Contributed Talk: Product form and insensitivity in networks of symmetric queues with random permutations
Authors: *T. Bonald* and *M-A. Tran*

15:05 – 15:30 Contributed Talk: Analysis of polling systems with two-stage gated service
Authors: *R.D. van der Mei* and *J.A.C. Resing*

15:30 – 15:55 Contributed Talk: Optimal stochastic scheduling in a general tandem queue with flexible servers
Authors: *J. Weichbold* and *K. Schiefermayr*

Session We-R16b – Chair: B.D. Choi

13:50 – 14:40 Invited Talk: **Multi-server queueing systems with cooperation of the servers**
Authors: *A.N. Dudin* (Belarusian State University, Belarus), *M.H. Lee*, *C.S. Kim* and *V.I. Klimenok*

14:40 – 15:05 Contributed Talk: Ambulance allocation and performance
Author: *J. van der Wal*

15:05 – 15:30 Contributed Talk: The minimum cross-entropy method in rare event simulations
Authors: *A. Ridder* and *R. Rubinstein*

15:30 – 15:55 Contributed Talk: Analysis and design of a play-out buffer for VBR streaming video
Authors: *K. Laevens*, *B. Steyaert*, *D. De Vleeschauwer* and *H. Bruneel*

16:00 – 16:30 Coffee Break

Session We-R15c – Chair: I. Mitrani

16:30 – 16:55 Contributed Talk: Delay moments in polling systems
Authors: *E.M.M. Winands*, *I.J.B.F. Adan* and *G.J. van Houtum*

16:55 – 17:20 Contributed Talk: The delayed acquisition queue
Authors: *D. Denteneer*, *J.S.H. van Leeuwaarden* and *I.J.B.F. Adan*

17:20 – 17:45 Contributed Talk: Consecutive customer losses in regular and oscillating $M^X/GI/1/n$ and $GI^X/M/1/n$ systems
Authors: *A. Pacheco* and *H. Ribeiro*

Session We-R16c – Chair: E. Morozov

16:30 – 16:55 Contributed Talk: Quantitative stability in $M/G/1//N$ queue with single server vacation: The strong stability method
Authors: *F. Rahmoune* and *D. Aissani*

16:55 – 17:20 Contributed Talk: Busy-period type of equation for the Google PageRank distribution
Authors: *N. Litvak*, *W.R.W. Scheinhardt* and *Y.V. Volkovich*

17:20 – 17:45 Contributed Talk: On the fluid limit of the $M/G/\infty$ queue
Authors: *C. Fricker* and *R. Jaibi*

July 6, 9:30 hours to 13:50 hours
Room "Salón de Actos": Session Th-SA
Room 15: Session Th-R15
Room 16: Session Th-R16

Session Th-SA – Chair: G. Latouche

9:30 – 10:20 Invited Talk: **The matrix analytic approach to stochastic fluid flow models**
Authors: *S. Ahn* and *V. Ramaswami* (AT&T Labs Research, USA)

Session Th-R15 – Chair: A. Krishnamoorthy

10:30 – 10:55 Contributed Talk: Transient analysis of a single server queue with catastrophes, failures and repairs
Authors: *B. Krishna Kumar*, *A. Krishnamoorthy*, *S. Pavai Madheswari* and *S. Sadiq Basha*

10:55 – 11:20 Contributed Talk: The $M/G/1$ queue under the dyadic (N, D)-policy and its cost optimization
Authors: *H.W. Lee* and *W.J. Seo*

11:20 – 11:45 Contributed Talk: Geometric probability and $M/M/\infty$ queues in random environment
Author: *B. D'Auria*

11:45 – 12:10 Contributed Talk: Generalized threshold policies for a push pull queueing system
Authors: *A. Kopzon* and *G. Weiss*

Session Th-R16 – Chair: V. Ramaswami

10:30 – 10:55 Contributed Talk: Analysis of IEEE 802.11 non-saturated DCF by matrix analytic methods
Authors: *Y.H. Bae*, *K.J. Kim*, *M. Moon* and *B.D. Choi*

10:55 – 11:20 Contributed Talk: Markovian fluid queues with upward jumps – A connection to Markov chains of $M/G/1$-type
Authors: *H. Masuyama* and *T. Takine*

11:20 – 11:45 Contributed Talk: Matrix exponential distributions with minimal coefficient of variation
Authors: *T. Elteto*, *S. Racz* and *M. Telek*

11:45 – 12:10 Contributed Talk: Computing the exact loss rate in a two-class finite capacity priority queue
Authors: *J. van Velthoven*, *B. van Houdt* and *C. Blondia*

12:20 – 13:50 Lunch Time

14:00 – 18:15 Royal Palace Trip

21:15 – 23:00 Conference Dinner

July 7, 9:30 hours to 15:00 hours
Room "Salón de Actos": Session Fr-SA
Room 15: Session Fr-R15
Room 16: Session Fr-R16

Session Fr-SA – Chair: E. Altman

9:30 – 10:20 Invited Talk: **Service systems with impatient customers when system is down**
Author: *U. Yechiali* (Tel-Aviv University, Israel)

10:30 – 11:00 Coffee Break

Session Fr-R15 – Chair: U. Yechiali

11:00 – 11:50 Invited Talk: **Expected waiting time in polling systems with correlated vacations**
Authors: *E. Altman* and *D. Fiems*

11:50 – 12:15 Contributed Talk: Analysis of a bulk queue with multiple vacations and accessible batch service and closedown time
Author: *R. Arumuganathan*

12:15 – 12:40 Contributed Talk: Equilibrium in the $M/G/1$ system with two types of vacation
Author: *L. Lakatos*

12:40 – 13:05 Contributed Talk: Pricing and equilibrium behavior for a Markovian queue with setup times
Authors: *A. Burnetas* and *A. Economou*

13:05 – 13:30 Contributed Talk: On the analysis of extreme values of some two-dimensional Markovian queues
Author: *J.R. Artalejo*

Session Fr-R16 – Chair: A.N. Dudin

11:00 – 11:50 Invited Talk: **Performance analysis of IEEE 802.11 series in non-saturated condition**
Author: *B.D. Choi*

11:50 – 12:15 Contributed Talk: Performance analysis of an uplink scheduling algorithm for VoIP service in IEEE 802.16d/e system
Author: *J.W. Um*, *B. Kim*, *K.J. Kim* and *B.D. Choi*

12:15 – 12:40 Contributed Talk: Optimal control of a large dam
Author: *V.M. Abramov*

12:40 – 13:05 Contributed Talk: Priority queues with self-generation of priorities
Authors: *A. Krishnamoorthy* and *V.C. Narayanan*

13:45 – 15:00 Lunch Time

Abstracts

In this section, abstracts are listed in alphabetical order of the first author.

Location-allocation of service units on a congested network

R. Aboolian, O. Berman, Z. Drezner

Abstract.– We consider the problem of locating facilities and allocating servers on a congested network (LASCN). Demands for service that originate from the nodes are assumed to be Poisson distributed and the servers provide service time that is exponentially distributed. The objective is to minimize the total cost of the system which includes fixed installation cost, variable server cost, cost associated with travel time and cost of waiting time in the facility for all the customers. The problem formulated as a nonlinear programming is analyzed. Results for exact and approximate solution approaches are reported. We also show that we can modify the approaches to solve the LASCN with constraints limiting both the travel time to the servers and the waiting time of customers.

Optimal control of a large dam

V.M. Abramov

Abstract.– We study a large dam model. The parameters L^{lower} and L^{upper} are its lower and upper levels, $l = L^{upper} - L^{lower}$ is large, and if current level of water is between these bounds, then the dam is assumed to be in normal state. Passage one or other bounds leads to damage. It is assumed that inflow of water is described by Poisson process, while outflow is state-dependent as follows. If the current level of water exceeds the level L^{upper}, then inverse flow rate (the time between per unit volume of water) has probability distribution $B_2(x)$, and if the dam is in a normal state, then the inverse flow rate has probability distribution $B_1(x)$. If the level of wa-

ter is exactly L^{lower}, then the outflow process of water is frozen, and it is resumed again as soon as the level of water exceeds the value L^{lower}. It is assumed that under- and over-flow damages the dam. Specifically, suppose $p_1 = \lim_{t\to\infty} P\{L_t = L^{lower}\}$, $p_2 = \lim_{t\to\infty} P\{L_t > L^{upper}\}$ exist. Then expected damage per time unit $J = p_1 J_1 + p_2 J_2$ is a performance measure (J_1 and J_2 are the corresponding damage costs associated with passage the bounds), and the aim is to determine parameter controlling the output stream of inverse flow rate in normal state such that the damage J is minimized.

A simple Markovian re-entrant line with infinite supply of work under the LBFS policy

I.J.B.F. Adan, G. Weiss

Abstract.– We consider a two machine 3 step re-entrant line, with an infinite supply of work. The service discipline is last buffer first served. Processing times are independent and exponentially distributed. We analyze this system, obtaining steady state behavior and sample path properties.

The matrix analytic approach to stochastic fluid flow models

S. Ahn, V. Ramaswami

Abstract.– Ramaswami demonstrated an interesting connection between Markov modulated fluid flow models and quasi birth and death processes and used it to develop a powerful scheme to compute the steady state results for fluid flow models based on the matrix-geometric approach to QBDs. Since then much work has happened using this line of approach on time dependent results, passage times, and duality based on time reversal. We shall review these deveopments with a particular emphasis on more recent results related to duality and computational issues.

Expected waiting time in polling systems with correlated vacations

E. Altman, D. Fiems

Abstract.– Polling systems have been extensively studied, and have had many applications. They have often been used for studying wired local areas networks (such as token passing rings) and wireless local area networks (such as bluetooth). In this work we relax one of the main restrictions on the statistical assumptions under which polling systems have been analyzed. Namely, we allow correlation between walking times.

We consider (i) the gated regime were a gate closes whenever the server arrives at a queue. He then serves at that queue all customers who were present when the gate closes. (ii) the exhaustive service in which the server remains at a queue till it empties.

Our analysis is based on stochastic recursive equations related to branching processes with migration with a random environment. These have been introduced at the previous ICQT conference and have made it possible to study the expected waiting time of a single queue with vacations. This was later extended to some polling systems with two queues by reducing the problem to a one dimensional problem, but this approach did not extend to more than two queues where one needs to derive second order properties of the stochastic recursive equations.

In addition to our derivation of expected waiting times for polling systems with correlated vacations, we set the foundations for computing second order statistics of the general multi-dimensional stochastic recursions.

Sojourn times in a perturbed $M/M/1$-PS queue

N. Antunes, C. Nunes, A. Pacheco

Abstract.– We consider an $M/M/1$-PS queue, with one permanent elastic flow, whose transmission capacity depends on an ergodic Markov process and a small positive parameter u. For such a system, we analyze the impact of the perturbation parameter on the mean sojourn time of an elastic flow.

Specifically, we derive the first two terms of the power series expansion in u of the mean sojourn time. The first order term is consistent with reduced service rate (RSR) approximation, which corresponds to the service rate for elastic flows being constant and equal to the mean value of the perturbed service rate. The complexity of the expansion increases for the second order term and correlations created by the unresponsive traffic appear. Qualitative results show that variability in the service rate degrades the performance of elastic flows.

On the analysis of extreme values of some two-dimensional Markovian queues

J.R. Artalejo

Abstract.– Two-dimensional continuous-time Markov chains are useful tools for studying stochastic models such as queueing, inventory and production systems. Of particular interest is the distribution of the maximal level visited in a busy period because this descriptor provides an excellent measure of the system congestion. We present an algorithmic analysis for the computation of its distribution which is valid for Markov chains with general-block

structure. For several multiserver retrial queues and other queueing models, we exploit the underlying internal block structure and present numerical examples that reveal some interesting facts of the systems.

Analysis of a bulk queue with multiple vacations and accessible batch service and closedown time

R. Arumuganathan

Abstract.– This paper deals with a single server non-Markovian bulk queue and accessible batch service. We derive the expected queue length of $M^X/G(a,d,b)/1$ with multiple vacations and accessible batches. The service starts only if minimum of 'a' customers available in the queue. At the server initiation epoch if the number of customers is $a \leq x \leq d-1$, then the server takes the entire queue for batch service and admits the subsequent arrivals in the batch while the service is on, till the service of the current batch is over or till the accessible limit d is reached, while ever occurs first. At the service initiation epoch if the number of customers waiting in the queue 'x' is at least 'd', $(a \leq d \leq b)$, the server takes $min(x,b)$ customers for service and does not allow further arrival into the batch. After finishing a service if the queue length is less than 'a', the server does some closedown job, then leaves for a vacation of random length. When he returns, if the queue length is still less than 'a', he leaves for another vacation and so on, until he finally finds at least 'a' customers waiting for service. Using supplementary variables technique the probability generating function of the steady state queue size at an arbitrary time is obtained. An expression for expected queue length is derived. Expected length of busy and idle period is obtained. A cost model is developed. Numerical results for a particular case of the model are also presented.

SQF: A slowdown queueing fairness measure

B. Avi-Itzhak, H. Levy, E. Brosh

Abstract.– Expected slowdown has been proposed as a *criterion* to evaluate queue fairness. This is based on the underlying belief that equating the slow-down of different customers is fair. Nonetheless, the prior work on this subject yielded only an always-fair / sometimes-fair / never-fair criterion which does not allow to compare the relative fairness of scheduling policies.

In this work we examine how the constant slowdown principle can be used as a basis for a full scale *queueing fairness measure*. We propose the Slowdown Queueing Fairness (SQF) measure based on the principle that customers' waiting time should be proportional to their service time. We analyze its properties and examine how they react to both seniority and

service requirements. We also examine whether its behaviour fits intuition. Its values for a variety of single server scheduling policies are derived.

Analysis of IEEE 802.11 non-saturated DCF by matrix analytic methods

Y.H. Bae, K.J. Kim, M. Moon, B.D. Choi

Abstract.– In the IEEE 802.11 MAC layer protocol, the basic access method is the Distributed Coordination Function which is based on the CSMA/CA. Most of analytical performance proposed so far the IEEE 802.11 DCF has been done on saturation conditions. Unfortunately, the saturation assumption is unlikely to be valid in most real IEEE 802.11 networks. There have not been many analytic works in the non-saturation mode due to mainly analytic complexity of models. The necessities of analytic performance of IEEE 802.11 in non-saturation mode are mentioned in several recent papers. In this paper, we investigate the performance of IEEE 802.11 DCF in the non-saturation mode. We assume that packet arrival process to a station is a Poisson process. The stochastic behaviour of a single station is modelled by Markov chain of $M/G/1$ type. We derive the stationary distribution of the Markov chain by applying matrix analytic methods. We obtain the probability generating function of Head-Of-Line delay and channel access delay, and channel throughput. Numerical results show that as the number of competing stations increases, the mean channel access delay increases rapidly. Our results can be used for the call admission control under some delay constraints.

Merging and splitting autocorrelated arrival processes and impact on queueing performance

B. Balcioglu, D. Jagerman, T. Altiok

Abstract.– We have proposed a three-parameter renewal approximation to analyze splitting and superposition of autocorrelated processes. We define the index of dispersion for counts of an ordinary process used in a new and more accurate technique to estimate the third parameter. Then, we express this newly defined index of dispersion for the superposition in terms of the ordinary as well as the stationary indices of dispersion of the originally autocorrelated component processes. Hence, even if the superposition data is not observable, as long as sufficient information exists on component processes, the parameters of the proposed renewal approximation can be estimated accurately. The accurate renewal approximation of a general process helps sustain accuracy if it is split, by-passing the need to sample from branched processes. We have tested the impact of our approximation

on the accuracy of the mean waiting time, which compared favorably with simulation results of the original systems.

Staffing to maximize profit for call centers with alternate service level agreements

O. Baron, J. Milner

Abstract.– In order to ensure quality from outsourced call centers, customers sign service level agreements (S.L.A.'s) that state acceptable customer delays. We determine the profit maximizing staffing policy for alternate S.L.A.'s for an outsourced call center operating in an environment with uncertain demand and abandonment. We develop a heavy traffic regime incorporating aspects of both the Efficiency Driven and the Quality and Efficiency Driven regimes. Using this regime we approximate the probability that a customer's wait exceeds an acceptable delay, and the probability of meeting a service level measured by the percentage of customers served within the acceptable delay. Numerical experiments demonstrate a high degree of accuracy for the approximations and the resulting staffing levels. We show that an S.L.A. requiring a percentile of demand in a period to be acceptably served provides a more conservative staffing level than agreements based on either an individual's experience or the experience of all customers in a long horizon.

Sojourn time approximations in small homogeneous packet switches

P. Beekhuizen, D. Denteneer, I.J.B.F. Adan

Abstract.– Packet switches have been the topic of much research, and the delay caused by packet switches has been analyzed by for instance Karol et al. They, however, make the critical assumption that the switch size N (the number of ports) tends to infinity.

We present a model that can be used to approximate the sojourn time in a homogeneous (i.e., destinations of packets are uniform) packet switch with fixed packet sizes. We do this by translating the switch to a $Geo/G/1$ queueing model. We furthermore show that for small switches our approximation scheme is indeed an improvement over current models and that it leads to a relative error of only 2% in the sojourn time in case $N = 4$.

Product form and insensitivity in networks of symmetric queues with random permutations

T. Bonald, M-A. Tran

Abstract.– Since the pioneer work of Jackson, an intense research activity has been devoted to the study of queueing networks, with applications ranging from production lines to computer systems and communication networks. Specific attention has been paid to so-called product-form queueing networks, whose stationary distribution can be evaluated explicitly. As originally proved by Kelly, the stationary distribution of such networks does not depend on the service time distribution beyond the mean for a large class of *symmetric* disciplines, that includes the processor-sharing discipline and the preemptive-LIFO discipline considered by Baskett, Chandy, Muntz and Palacios. This insensitivity property is of great practical interest since usual performance metrics like the mean sojourn time of a customer at any given queue can be evaluated without knowing the precise statistics of service requirements.

In the present paper, we demonstrate that the product form and insensitivity properties of networks of symmetric queues are preserved when the positions of customers in each queue are *permuted at random* before each customer arrival and after each customer departure. We also show that these properties hold when customers are permuted across queues, provided the service time distribution is the same at all queues. The results are illustrated by a number of toy examples.

Sojourn times in queueing networks

O.J. Boxma

Abstract.– From a customer's point of view, the most important performance measure in a queueing network is his sojourn time.

We present a brief overview of the exact analysis of sojourn-time distributions in networks of queues. Particular attention is paid to product-form networks, for which exact expressions have been obtained for the joint distribution of a customer's sojourn time along a quasi overtake-free path.

In view of the fact that exact sojourn-time results can only be obtained under quite restrictive assumptions, we subsequently discuss asymptotic and approximative methods for studying sojourn times in queueing networks.

As an application, we consider sojourn times in a queueing-network model of a patent office.

On queues with service and interarrival times depending on waiting times

O.J. Boxma, M. Vlasiou

Abstract.– We consider a model that is an extension of the $G/G/1$ queue. This model is described by a non-monotone Lindley-type recursion. It repre-

sents the waiting time distribution in a first-come-first-served queue in which the service times and interarrival times depend linearly and randomly on the waiting times. Moreover, for specific parameter values, this model reduces either to the classical Lindley equation for the waiting time in the $G/G/1$ or it describes the waiting time of the server in an alternating service model. We derive the steady-state waiting-time distribution when the interarrival times are generally distributed and the service times follow a phase-type distribution, and when the interarrival times are exponentially distributed and the service times are deterministic.

Pricing and equilibrium behavior for a Markovian queue with setup times

A. Burnetas, A. Economou

Abstract.– We consider a single server Markovian queue with setup times. Whenever a customer leaves this system empty, the server departs immediately to attend to secondary jobs. On the contrary, whenever a customer arrives to an empty system, the server is recalled immediately and it takes an exponential setup time to start service again. We assume a natural reward - cost structure for the customers, which incorporates their desire for service as well as their unwillingness to wait.

We examine customers' behavior under various levels of information regarding the state of the system at arrival instances. More specifically, a customer may know or not know the state of the server and the number of present customers upon his arrival. We derive equilibrium strategies for the customers under the various levels of information and we study the associated social optimization and profit maximization problems. Analytical and numerical comparisons illustrate further the effect of the information level to the pricing and equilibrium behavior of the system.

Optimal admission control in tandem queues with blocking

A. Burnetas, W. Millhiser

Abstract.– We study the dynamic control of arrivals of multiple customer classes in two stage tandem queues with finite buffers and blocking after service. We formulate the problem as a Markov decision process and employ a state transformation that simplifies the state-space description. This allows several key admission control results from $M/M/N$ and $M/M/N/N$ queueing models to be extended to the present system. Specifically, we show that the net benefit of admitting a job declines monotonically with the system congestion, thus the decision to admit any job class is based on threshold values of the number of jobs present in the system. Furthermore, we derive

conditions under which a job class is always or never admitted, regardless of the system state.

Resource allocation in multi-site stochastic service systems

X. Chao

Abstract.– We study optimal resource allocation problem in multi-site stochastic service systems with inter-site customer flows, e.g., healthcare systems. The objective is to minimize overall system-wide average customer waiting times. The resulting optimization problem is sharply different from the classical resource allocation problem (e.g., Arrow, Ibaraki, etc.) and it involves queueing analysis, game theory, convex analysis, and mathematical program with equilibrium constraints (MPEC). We develop analytical models and obtain explicit closed form optimal allocation policy. We aim at providing insights to and guidelines for resource allocation in these service systems when some service criterion, such as average waiting time, loss rate, or blocking probability, is a major concern. Our results demonstrate that the commonly used proportional allocation rules are not optimal; instead the optimal resource allocation solution exhibits a structure of "a few large and many smalls".

Performance analysis of IEEE 802.11 series in non-saturated condition

B.D. Choi

Abstract.– We focus on performance analysis of IEEE 802.11 DCF and 802.11e EDCA, HCCA and 802.11n in non-saturation condition. We may classify three different models according to how the packets generate and are queued in a buffer. The first case is that the packets generated according to Poisson process and are queued in the infinite buffer. This model is investigated by Matrix analytic method or $M/G/1$ queueing system. The second case is that the flow is not generated during service and inter-arrival time of flow is exponential distributed. This model is investigated by modelling stochastic behaviour of one station as a discrete time Markov chain. The second case was studied by modelling the system with homogeneous stations as machine-repairman problem without comprising protocol details. This model can be extended to the system with heterogeneous stations where flow sizes and length of OFF-periods have different geometric distributions and different exponential distributions at different stations respectively. Performance analysis of IEEE 802.11n is discussed.

Probability of traffic loss in a backbone network with statistical

multiplexing, QoS differentiation and unicast/multicast routing

G.L. Choudhury

Abstract.– We develop an exact analytic model to compute the class-specific probability of traffic loss over a bottleneck backbone link of a broadband network with zero buffers (simulation comparison with non-zero buffers). There are several classes of traffic and they are provided Quality of Service (QoS) treatment based on either Generalized Processor sharing (GPS), or strict priority, or a combination. GPS is a good approximation to the actual QoS scheduling mechanisms used by Routers and Switches, e.g., Weighted Fair Queueing and Modified Deficit Round Robin. Traffic for each class consists of several types of flow. Each type of flow arrives according to a Poisson process, is characterized by a constant data rate, and the flow duration has a general distribution including heavy-tailed ones. It is well known that the arrival process of individual packets is usually strongly non-Poisson but Poisson flow arrivals with heavy-tailed flow duration distribution is a good approximation for Internet traffic. Different data rates for different flow types are allowed. A very large number of flow types are computationally feasible by deriving a generating function expression and by developing an efficient numerical-transform-inversion-based and recursion-based solution methods. Next the solution is generalized to a network using either unicast routing (OSPF or ISIS) or multicast routing (PIM-SM or PIM-SSM). For a small number of links exact solution is computationally feasible but with a large number of links an approximate solution is developed by treating each link independently.

Zero-automatic networks

T-H. Dao-Thi, J. Mairesse

Abstract.– Zero-automatic queues are a new model characterized by a special buffering mechanism evolving like a random walk on some infinite group or monoid. The salient result is that all 0-automatic queues are quasi-reversible. The $M/M/1$ queue, and Gelenbe's G-queue with positive and negative customers are the two simplest 0-automatic queues. The $M/M/1$ queue (respectively G-queue) is the basic primitive for building Jackson networks (respectively G-networks), which have the remarkable property of having a "product-form" stationary distribution. We introduce Jackson-type networks of 0-automatic queues. We prove that such networks always have a "product-form" stationary distribution.

Geometric probability and $M/M/\infty$ queues in random environment

B. D'Auria

Abstract.– We consider $M/M/\infty$ queues where the server speeds will depend on an independent finite state Markov process. For these systems we show that to compute the stationary number of customers in the system is equivalent to evaluate the area of a random set in $\mathbb{R}^2$. We will use a recursive argument to compute this area and we show that for some cases it can be expressed with explicit formulas.

A fixed point iteration scheme for closed queueing networks with phase-type service distributions and arbitrary buffer sizes

T. Dayar, A. Meriç

Abstract.– Today, obtaining various performance measures for queueing networks still remains a challenging problem. Indeed, only a small class of queueing networks can be analyzed easily and exactly for their performance measures. This class of networks is called product form and requires specific Markovian conditions on the arrival and service processes. On the other hand, obtaining performance measures for networks of queues with general arrival and service time distributions and arbitrary buffer sizes is difficult. Closed queueing networks with phase-type service distributions are among these kinds of networks. The techniques used to analyze them are mostly approximative and based on decomposition due to the sizes of the underlying state spaces. In this paper, we extend a fixed point iteration scheme based on decomposition for closed queueing networks with Coxian service distributions and arbitrary buffer sizes from the literature to include phase-type service distributions and show how the irreducible Markov chain associated with each subnetwork in the decomposition can be represented hierarchically using Kronecker products. The proposed method is implemented in a software tool; it is compared with other solution techniques for accuracy and efficiency on a number of examples using the tool; and its convergence properties are discussed.

Performance analysis of a discrete-time queue with multiple reservations

S. De Vuyst, S. Wittevrongel, H. Bruneel

Abstract.– We analyse a discrete-time queueing model with packet arrivals that are either classified as delay-sensitive (*type 1*) or delay-tolerant (*type 2*). The queue has a single server and each packet requires a service time of one slot. The prominent feature of this model is its reservation-based queueing discipline, which has the purpose of reducing the queueing delay perceived

by the 1-packets, at the cost of allowing higher delays for the 2-packets. A traditional approach is to give Absolute Priority (AP) to the packets of type 1, i.e. to serve 2-packets only when no 1-packets are available. With AP however, the delay difference may be too drastic and cannot be controlled.

Our solution is to introduce a total of N reserved places in the queue, intended for future arrivals of type 1. Specifically, whenever a 1-packet enters the queue, it takes the position of the most advanced reservation and creates a new reservation at the end of the queue. Type 2 arrivals on the other hand, are always stored in the usual FIFO (First-In First-Out) manner. This way, it is possible for a 1-packet to jump over already queued 2-packets, resulting in the desired prioritization. Note that per-type FIFO operation is guaranteed, while the amount of stochastic delay difference between 1- and 2-packets can be smoothly controlled by the parameter N.

As a result of our analysis, we obtain the probability generating function, the mean value and the tail distribution of the delay experienced by both 1- and 2-packets. In each case, fast computational algorithms are provided, as well as sample numerical examples.

The delayed acquisition queue

D. Denteneer, J.S.H. van Leeuwaarden, I.J.B.F. Adan

Abstract.– We propose a new queueing model entitled the delayed acquisition queue. It differs from conventional queueing models in the sense that the server needs to perform acquisition of customers. The server has to divide its energy between either serving customers presently waiting or performing acquisition of new customers. The number of newly acquired customers is uncertain, and the effect of the server's present acquisition efforts can only be seen after some fixed time period D (delay).

The delayed acquisition queue constitutes a $(D+1)$-dimensional Markov chain. One of its key features is that the server performs more acquisition when the queue is small, and due to the delay D, the queue length process shows a strongly cyclic behavior.

We propose and investigate several ways of planning the acquisition efforts. In particular, we propose an acquisition scheme that is designed specifically to reduce the cyclic behavior of the queue length process.

Multi-server queueing systems with cooperation of the servers

A.N. Dudin, M.H. Lee, C.S. Kim, V.I. Klimenok

Abstract.– Multi-server queueing systems with possible cooperation of the servers are presented and discussed. Cooperation assumes an opportunity of simultaneous service of a customer by all servers available at an arrival

epoch. Variants when the servers handle the independent copies of the customer and when the work relating to a service of the customer is uniformly shared among all involved servers are considered. The first variant suits well for description of the communication systems with broadcasting. The second one describes operation of MIMO (multiple input - multiple output) communication systems. Queueing systems of the $SM/PH/N$, $SM/PH/N/0$, $SM/PH/N/R$, $MAP/PH/N$, $MAP/PH/0$, $MAP/PH/N/R$ type are under study. Stationary distributions of queue length, waiting and sojourn times as well as the main performance measures are calculated. Profit provided by the servers cooperation is explained and numerically illustrated for the cases of absolutely reliable and non-reliable servers operation. Systems with the controlled use of cooperation are analyzed as well.

Tail behaviour of conditional sojourn times in processor-sharing queues

R. Egorova, B. Zwart

Abstract.– The tail asymptote for the sojourn time distribution in the $M/M/1$ PS queue is known to be of complicated form, seems difficult to extend to more general PS queues, and is not precise enough to serve as approximation. Motivated by this, we investigate the asymptotic behavior of the sojourn time distribution for a request of given length in the $M/G/1$ PS queue. In particular, we prove that the sojourn time asymptotics are of purely exponential type for a queue with general service time distribution in two special cases: (i) when the traffic load is sufficiently high and (ii) when the size of the request of the tagged customer is sufficiently small. We next turn our attention to the $M/M/1$ PS queue. Using the branching process technique we derive exponential asymptotics for all values of the load and the job size. We obtain an equation for the asymptotic decay rate and an explicit (though complicated) expression for the asymptotic constant. We show that the exponential asymptote is an accurate approximation of the conditional sojourn time distribution for moderate values of x. Finally, we analyze the behavior of the decay rate depending on the request length and compare it with decay rates for an $M/M/1$ system with different service discipline such as FCFS, LCFS and SRPT.

Matrix exponential distributions with minimal coefficient of variation

T. Elteto, S. Racz, M. Telek

Abstract.– The minimal coefficient of variation of order n phase type distributions are known to be $1/n$. There are examples of order n matrix

exponential distributions with lower coefficient of variation than $1/n$. In this paper we investigate the structure of matrix exponential distributions that exhibits minimal coefficient of variation. It turns out that the number of complex conjugate eigenvalue pairs plays important role in minimizing the coefficient of variation. We provide a minimal structure for order n matrix exponential distribution with a given number of complex conjugate eigenvalue pairs.

The minimal coefficient of variation of order n ($n > 2$) matrix exponential distributions is significantly less than the one of order n phase type distribution and it decreases with the increasing number of complex conjugate eigenvalue pairs. For example the coefficient of variation of order 5 matrix exponential distributions could be less than the one of the order 10 Erlang distribution.

Matrix exponential distributions with low coefficient of variation find important applications, e.g., in numerical analysis of non-markovian stochastic models with deterministic or very low variance delays.

On the analysis of batch arrival $GI/M/./.$ queues with state dependent service rates and a class of customer acceptance policies

F. Ferreira, A. Pacheco

Abstract.– We propose an approach that combines embedding, uniformization and stochastic ordering techniques to analyze batch arrival $GI/M/./.$ queues with state dependent service rates and customer acceptance policies that are stochastically increasing on the size of the arriving batch. The method is effective in practice for a large range of finite buffer queues with interarrival time distributions for which it is possible to evaluate the associated mixed-Poisson probabilities. The proposed approach produce results with any desired precision level and works well in some situations that other methods do not deal well with, as illustrated through numerical examples.

On the fluid limit of the $M/G/\infty$ queue

C. Fricker, R. Jaibi

Abstract.– The paper deals with fluid limits of generalized $M/G/\infty$ queues with the heavy-traffic scaling. The target application is the modelling of Internet traffic at a flow level. It has been observed from measurements that, in a suitable model, flows can be considered as customers of independent $M/G/\infty$ queues in heavy traffic. The paper gives a simplified approach of fluid limits of such processes in case of Poisson arrivals. Expressing the state process as a functional of a Poisson point process, an elementary proof for such limit theorems is given. It is based on martingales techniques and

weak convergence results. Within this framework, this paper clarifies the classical heavy-traffic limit theorems for the $G/G/\infty$ queue developed earlier by Iglehart and Borokov then by Krichagina and Puhalskii. Moreover the expressions obtained for the limits are used to give asymptotics in terms of the key parameters of a model of Internet traffic where the distributions of the flow transmission duration are heavy-tailed.

Randomized approximation scheme and perfect sampler for closed Jackson networks

S. Kijima, T. Matsui

Abstract.– In this talk, we propose a polynomial-time randomized approximation scheme for calculating the normalizing constant of the product form solution of closed Jackson networks. Our algorithm is based on Markov chain Monte Carlo (MCMC) method. We also propose two efficient sampling algorithms for closed Jackson networks.

The Jackson network is one of the basic models of the queueing network theory, and has a product form solution as the equilibrium distribution of the state of customers in the network. There is well-known Buzen's algorithm for computing the normalizing constant. However, it is a pseudo-polynomial time algorithm and thus the running time increases proportional to the number of customers in the network. For very special cases, Chen and O'Cinneide proposed a genuinely polynomial time randomized algorithm.

Our algorithm is genuinely polynomial time algorithm. More precisely, the time complexity is bounded by a polynomial of the number of nodes and the logarithm of the number of customers. The size of error of an approximate value obtained by our algorithm satisfies a given bound of error rate. We propose two of new ergodic Markov chains, whose stationary distributions are the product form solution of closed Jackson networks. One is for genuinely polynomial time approximate sampler, i.e., the mixing time is bounded by a polynomial of the number of nodes and the logarithm of the number of customers. The other is for perfect sampler based on monotone coupling from the past (CFTP) algorithm, which generates a state exactly according to the stationary distribution.

A queueing system with discrete autoregressive arrivals of order p

B. Kim, K. Sohraby

Abstract.– Discrete autoregressive arrival models are described by a few parameters and provide a simple mean to obtain analytical models for matching the first and the second order statistics of the measured data. De-

spite the simplicity of the discrete autoregressive arrival models, there has been a very few analysis of queueing systems with such arrivals. Further, all results are on queueing systems with DAR(1) (Discrete AutoRegressive process of order 1). Also DAR(1) can be too restrictive for traffic modelling because it can reflect only geometric autocorrelation functions. On the other hand, DAR(p) (Discrete AutoRegressive process of order p) has much more flexibility in the correlation structure, but there are no known analytic results on queueing systems with DAR(p).

In this work, we consider a discrete time queueing system where one customer (cell) per slot is transmitted, and the arrival process is governed by DAR(p) characterized by an arbitrary stationary batch size distribution and a correlation function. We obtain the mean queue size and the mean waiting time for the queue. The tail behavior of the queue length and waiting time distributions are also examined. In particular, we generalize some results on the queueing model with DAR(1) by showing that unlike the classical queueing models with Markovian arrival processes, the correlation in the DAR(p) model results in a non-geometric tail behavior of the queue occupancy (and the waiting time) if the stationary distribution of the DAR(p) has an infinite support. A complete characterization of the geometric tail behavior of the queue occupancy (and the waiting time) is presented showing the impact of the stationary distribution and the correlation coefficient when the stationary distribution of the DAR(p) has a finite support.

Performance analysis of IEEE 802.11 DCF and IEEE 802.11e EDCA in non-saturation condition

T.O. Kim, K.J. Kim, B.D. Choi

Abstract.– We focus on performance analysis of IEEE 802.11 distributed coordination function (DCF) and IEEE 802.11e enhanced distributed channel access (EDCA) with considering protocol details in non-saturation condition at both packet level and flow level. There have not been many analytic works in non-saturation condition due to mainly analytic complexity of models. However, non-saturation is valid in most real WLAN network. In this paper, we deal with the non-saturation case that the flow is not generated during which the previous flow is in service and flow size is geometrically distributed. This case occurs when a user wants to transmit files in a WLAN area. Our approach is to model stochastic behaviour of one station as a discrete time Markov chain by substantially revising and extending the analytical model developed by Bianchi for the performance analysis of DCF in saturation condition. We obtain four performance measures: channel throughput, packet average delay, packet loss probability and flow service completion time. Our results can be used for call admission control to find optimal number of stations with some constraints on these measures.

Service level and monotonicity in call center queueing models

G. Koole

Abstract.– The standard service level definition in call centers, the percentage of callers that wait less then a certain threshold, has a number of disadvantages. It stimulates the "rational" manager to take undesirable actions, and, mathematically speaking, it has a number of counterintuitive properties. We discuss both the practical as well as the mathematical issues and discuss what other definitions can be used.

Generalized threshold policies for a push pull queueing system

A. Kopzon, G. Weiss

Abstract.– We consider a multiclass queueing system with two service stations and four classes, where there are two streams of customers, one stream is processed first in station 1 and then in station 2, the other stream moves in the opposite direction. This push pull system is distinguished from the network of Rybko and Stolyar in that be assume that there is an unlimited number of customers available in each of the two streams. Hence, both service stations can be busy all the time, i.e. work at utilization $\rho = 1$. We assume processing times are memory-less. We find a family of generalized threshold policies for which this system is stable, i.e. positive recurrent, with this full utilization. We derive the steady state distribution for some of these policies.

Transient analysis of a single server queue with catastrophes, failures and repairs

B. Krishna Kumar, A. Krishnamoorthy, S. Pavai Madheswari, S. Sadiq Basha

Abstract.– A transient solution is obtained analytically using continued fractions for the system size in an $M/M/1$ queuing system with catastrophes, server failures and non-zero repair time. The steady state probability of the system size are also presented. Some key performance measures, namely, throughput, loss probability and response time for the system under consideration are investigated. Further, reliability and availability of the system are analysed. Finally, numerical illustrations are used to discuss the system performance measures.

Priority queues with self-generation of priorities

A. Krishnamoorthy, V.C. Narayanan

Abstract.– We consider an n-priority queueing system in which customers arrive according to Marked Markovian processes. p_k is the probability of the arrival belonging to priority k, $k = 2, ..., n$. While waiting for service customers change there priority according to an exponentially distributed time. There will not be any change of priority for customers of the highest priority. Also while waiting for service customers do not change priority. Service times of customers follow independent and identically distributed phase type distribution. Except the nth priority all other priority waiting spaces are restricted to be finite. The long run behaviour of the system is numerically investigated. A number of system performance measures are obtained. The results are numerically illustrated.

Analysis and design of a play-out buffer for VBR streaming video

K. Laevens, B. Steyaert, D. De Vleeschauwer, H. Bruneel

Abstract.– A critical component in the delivery of VBR streaming video over packet-based networks, is the play-out buffer at the receiver side. As packets will incur a variable delay within the network, a mechanism is needed to dejitter the stream and assure that packets are played out at exactly the same rate at which they were generated by the sender. This can be realized by delaying the start of the stream at the receiver side for a sufficiently long time - the so-called dejitter time - so that not too excessive network delays can be absorbed. Evidently, this requires some buffer memory, which should be sufficiently large to avoid packet loss.

We first identify the conditions for underflow and overflow, i.e., the loss of packets due to lateness and buffer overflow respectively. As expected, the probabilities of these events strongly depend on the network-delay characteristics. Therefore, we take a closer look at the case where a single bottleneck exists within the network, and derive approximate formulae for them. Simulation is used to verify these analytic results.

From the analysis, we are also able to derive useful design rules. We consider two cases, depending on whether or not the receiver has knowledge about the delay the first packet of the stream has incurred. We conclude the paper with a cautionary note on the possible impact that correlation in subsequent packet delays may have on the probability of loosing consecutive packets due to underflow.

Equilibrium in the $M/G/1$ system with two types of vacation

L. Lakatos

Abstract.– It is a classical result the generating function of equilibrium distribution in the $M/G/1$ system obtained by using the embedded Markov chain technique. From it one can get the ergodic probabilities by means of differentiation, but this method leads to very complicated expressions.

At the end of 80's there appeared papers from some authors (Briere, Chaudry [1,2], etc.) who proposed other approaches, more convenient from computational viewpoint, under certain conditions for the solution of this problem.

We use another method based on the theory of regenerative processes [3]. It gives possibility to find the ergodic probabilities on the basis of mean value of a regenerative cycle and the mean value of times spent in different states for it [4]. Here we present a recursive algorithm determining these mean values in the $M/G/1$ system with vacations at the beginning and at the end of the busy period.

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Discrete-time $BMAP/PH/1$-type queues analyzed as QBDs

G. Latouche, M.A. Remiche, G. Renard

Abstract.– We consider systems in discrete-time which behave smoothly over intervals of time with an occasional jump upwards at certain epochs. Applications are the classical number-in-queue process of the $BMAP/PH/1$ queue and also its work-in-system process. More specific illustrations are models for MPEG-4 video transmission over wireless links; indeed, discrete BMAPs have been shown to be useful in modeling video frame size, type and time correlation.

We show that if the jumps of the process have a phase-type description, then the stationary distribution may be determined from an auxiliary QBD process, for which very efficient algorithmic approaches exist.

The $M/G/1$ queue under the dyadic (N, D)-policy and its cost optimization

H.W. Lee, W.J. Seo

Abstract.– In this talk, we consider the $M/G/1$ queueing system under the $Min(N, D)$-policy in which the idle server resumes its service if either N customers accumulate in the system or the total backlog of the service times of the waiting customers exceeds D, whichever occurs first.

We first analyze the queue length, the workload and the waiting time. Then, we consider two linear cost models (one based on the mean workload and the other based on the mean queue length) and compare the optimal $Min(N, D)$-policy with the optimal N-policy and the optimal D-policy.

Busy-period type of equation for the Google PageRank distribution

N. Litvak, W.R.W. Scheinhardt, Y.V. Volkovich

Abstract.– PageRank is a notion used by Google to rank the web pages. The PageRank is defined as the stationary distribution of a Markov chain that models a surfing process of an 'easily bored' surfer. At each step, the surfer either follows a randomly chosen hyperlink or simply jumps to a random page. In such a model, the PageRank is closely related to the number of incoming links (in-degree) of a page. Experiments confirm that the PageRank and the in-degree distributions exhibit strikingly similar tail behaviour. We propose a stochastic model that explains this similarity. The connection between PageRank and in-degree is modelled through a distributional identity analogous to the equation for the busy period of the $M/G/1$ queue.

Third generation mobile customer network

F. Machihara

Abstract.– In mobile customer networks, the customers may be unwilling to meet the hand-off failure rather than the call blocking, because services being enjoyed by them are unexpectedly interrupted and broken down. The third generation mobile networks can give some priority to mobile active customers who are getting into the tagged cell over inactive customers in order to prevent the hand-off failures. Even if a mobile active customer who is getting into the tagged cell meets all circuits being busy, his service is never interrupted. He can continue to hold his circuit in the pre-existing cell, until a circuit becomes free in the tagged cell. However, instead of being able to decrease the hand-off failure probability, the blocking probability for inactive customers increases. We evaluate the blocking probability and call right and/or wrong of the third generation system.

A priority scheduling discipline with controlled priority jumps

T. Maertens, J. Walraevens, H. Bruneel

Abstract.– A common feature encountered in modern communication networks is competition for limited capacity, by types of traffic with different Quality of Service (QoS) characteristics. E.g. real-time traffic has strict delay requirements, while for non-real-time traffic, real-time delivery is not a primary concern. Priority scheduling disciplines, in which multiple priority levels are provided and different priority levels are given to different types of traffic, may help achieve differentiation in QoS. In the static head-of-the-line (HOL) priority scheme, priority is always given to real-time traffic, i.e., this high-priority traffic is always scheduled for service before non-real-time, low-priority traffic. In a dynamic priority scheduling discipline, high- and low-priority traffic are either served alternately, or low-priority packets are allowed to jump to the (logical) high-priority queue. Within this context, we consider a discrete-time, two-class queueing system with two priority queues of infinite capacity and with one server. Packets are served through the HOL-JIA (head-of-the-line, jump-if-arrival) priority scheme: at the end of each slot in which a low-priority packet arrives at the system, the packet at the HOL-position of the low-priority queue jumps to the high-priority queue. By introducing this jumping condition, we let low-priority traffic flow into the high-priority queue, in a controlled manner (i.e., depending on the input). By means of the probability generating function method, we analyze the system contents of both queues, and the delays of both types of packets. Especially, the analysis of the low-priority delay proves challenging. Finally, the HOL-JIA scheduling is compared with other scheduling types.

Queues with advance reservations

R.J. Maillardet, P.G. Taylor

Abstract.– Queues where on "arrival" customers make a reservation for service at some time in the future are endemic in practice and relatively underanalysed in theory.

Simulations illustrate some interesting implications of the facility to make such reservations. For example introducing independent and identically distributed reservation periods into an Erlang loss system increases the blocking probability above that given by the Erlang B formula, thus degrading system throughput (despite the fact that the process of 'reserved arrivals' is still Poisson).

In this talk we shall discuss some preliminary attempts to analyse such queues. In particular, we shall obtain various transient and stationary distributions associated with the "bookings diary" for the infinite server system,

and discuss attempts to extend the analysis to the finite server case.

Transient and asymptotic periodic solution to the quasi-birth-death process with time-inhomogeneous transition rates

B. Margolius

Abstract.– Queueing processes often involve arrival or departure processes that vary with time. We study the transient distribution of the queue length process and its moments for the class of queues that can be modeled as quasi-birth-death processes with time-varying parameters. For those queues for which transition rates vary periodically, we also study the asymptotic periodic distribution (when it exists) of the queue length and its moments. We employ both generating function and sample path arguments to obtain these results.

Job transfers between queues with unreliable servers

S.P. Martin, I. Mitrani

Abstract.– We consider a system where incoming jobs may be executed at different servers, each of which goes through alternating random periods of being operative and inoperative. Neither the queue sizes nor the operative states of the different servers are known at moments of arrival. Hence, a load balancing mechanism that relies on random time-out intervals and job transfers from one queue to another is adopted. The object of the analysis is to determine the optimal settings for those intervals, in order to minimize a cost function which may include holding costs and transfer costs. First, an exact solution is obtained for a single-server queueing model with breakdowns, repairs and random reneging of jobs. That solution is then combined with an approximating assumption that the total arrival process into a queue, comprising external arrivals and transfers from other queues, is Poisson. That approximation, together with fixed-point iterations, enables the full model to be solved for any given transfer policy. Several such policies are evaluated and compared.

Markovian fluid queues with upward jumps – A connection to Markov chains of $M/G/1$-type

H. Masuyama, T. Takine

Abstract.– This paper considers Markovian fluid queues with upward jumps. In analyzing such a queue, probabilities associated with the first return to the initial level play an important role. Inspired by Ramaswami's work

(1999) on Markovian fluid queues without jumps, we correlate a fluid queue with upward jumps to a discrete-time Markov chain of $M/G/1$-type, and we show that the return probabilities are obtained as the G-matrix in the Markov chain of $M/G/1$ type. Thus the return probabilities can be computed efficiently with algorithms for the G-matrix (e.g., cyclic reduction algorithm). In addition, owing to the duality between a Markovian fluid queue with upward jumps and one with downward jumps, our result is applicable to the computation of the kernel of the matrix exponential distribution of the buffer content in the stationary Markovian fluid queue with downward jumps.

Multiclass Markovian fluid queues

H. Masuyama, T. Takine

Abstract.– This paper considers a multiclass Markovian fluid queue with a buffer of infinite capacity. Input rates of fluid flows in respective classes and the drain rate from the buffer are modulated by a continuous-time Markov chain with finite states. We assume that fluid in the buffer is drained according to the FIFO service discipline. Namely, all fluid arriving before time t has already been drained completely from the buffer when any fluid arriving after time t starts to be drained from the buffer. To analyze the FIFO multiclass Markovian fluid queue, we first convert the original fluid queue to a new fluid queue with constant drain rate of one, by change of time-scale. Next we introduce attained waiting time in fluid queues (which is an analogue of that for ordinary FIFO single-server queues), and we obtain the stationary distribution of the attained waiting time. We then show that for any time, the amount of fluid in the buffer is equal to that of fluid arriving during the attained waiting time. With these results, we derive the joint Laplace-Stieltjes transform (LST) for the amount of fluid in each class. Based on the LST, we develop a numerical procedure for the joint and marginal moments of the amount of fluid in the buffer. Some numerical examples are also provided.

Priority queueing systems with switchover (orientation) time: Results and open problems

G.K. Mishkoy

Abstract.– It is well known that disciplines related to priority servicing of different queues are widely spread in real time systems. In these systems switching between priority classes is necessary and inevitable. At the same time, in most theoretical research works it is assumed that switching between priority classes is instantaneous. However, in most real life systems

this does not hold: switching from a priority class to another is non-zero. Formalization and examination of switchover time lead to appearance of new models, called priority models with switchover (orientation) time or generalised models. The elaboration and study of such models are of a special interest from the theoretical point of view. Due to the fact that the models involving switching represent generalisations of the classical priority models, one can expect that the analytical results for such systems contain as particular cases the corresponding results for the classical systems. As will be shown, such a hypothesis is confirmed. We present some examples, and in particular a system of recurrent functional equations for the evaluation of the busy period of the generalised system. It will be shown that in the case when the switchover times are zero and there is only one class of the requests, one gets a well known Kendall-Takacs equation. When the number of priority classes is more than one, the mentioned system can be reduced to another known result obtained by Gnedenco et al. The same will be shown for the traffic coefficients and for the steady state conditions.

Stability analysis of regenerative queues

E. Morozov

Abstract.– We continue to develop a stability analysis of the regenerative queueing processes based on the renewal technique and an asymptotic property of the remaining renewal time generated by the regeneration points of the process. It has been established earlier that such approach turns out to be very effective in stability analysis of a wide class of queueing processes including general queueing feedforward networks. Moreover, this approach is extended to multiserver queues with nonidentical servers and some multiclass networks. In many cases this approach allows to obtain minimal sufficient stability conditions which are close to being necessary. For a queueing process (in discrete or continuous time) with the embedded renewal process of the regenerations, the following fact holds: the mean regeneration period is infinite if and only if the forward (remaining) regeneration time goes to infinity in probability as time increases. To apply this dichotomy, we develop a two-stage analysis. First, a negative drift condition is used to prove that the basic process visits a compact set infinitely often. Then we use a regeneration condition to establish that a regeneration occurs within a finite interval with a probability which uniformly lower bounded over the compact set by a positive constant. This implies the positive recurrence of the queueing process (finiteness of the mean regeneration period).

We apply this approach to a retrial queue with m identical servers, a renewal input of primary customers, a general service time distribution and exponential retrial times. We establish an asymptotic work-conserving property of this queue (as orbit size increases) and then extend well-known sta-

bility condition for a standard multiserver queue with infinite buffer (traffic intensity $< m$) to the retrial queue. Moreover, we discuss the applications of this approach to prove stability conditions of a tandem network with feedback admission control and a multiserver queue with a dependency between interarrival time, service time and unfinished workload.

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A recursion formula for a finite discrete-time queue and a related spectral method

S. Nishimura

Abstract.– In this paper, we derive a new recursion formula for a $D - BMAP/D/1/N$. Using this formula the boundary vector and the stationary probability vector of the number of customers in the system are calculated by a matrix analytic method. This method is quite different from the conventional methods as the $M/G/1$ type paradigm or the censoring technique but is an exact one derived from the structure of the transition probability matrix for a discrete-time queue. We consider a queueing system with a synchronous service process whose arrival process is a BMAP. Applying the formula to a synchronous $BMAP/D/1/N$, we obtain a spectral method calculating the stationary vector. The spectral method is based on the Cauchy integral on the unit circle.

As a numerical example we consider a BMAP with 9 phases estimated from count data of a bursty real IP traffic. Setting $N = 1000$, 2000 and 3000 for $\rho = 0.5$, the stationary vector of a synchronous $BMAP/D/1/N$ queue are precisely calculated and the corresponding loss probabilities are 9.760E-05, 3.707E-08 and 1.411E-11, respectively. Thus, since the stationary vector and the loss probability for a finite buffer queue are precisely calculated, the proposed method will be useful to an analysis of a real traffic.

A discrete-time queueing model in a random environment

R. Nobel

Abstract.– This paper presents a one-server queueing model in a random environment in discrete time, i.e. time is counted only in slots. The environment can be in two states, say green and orange. The environment switches, non-intermittently and independently from any other event, from green to orange and vice versa. The number of slots between two consecutive transitions of the environment follows a geometric distribution with a transition-dependent parameter. In every slot a generally distributed number (batch) of customers arrives, and the probability distribution of the

batch size depends on the actual state of the environment. The different numbers of arrivals in consecutive slots are mutually independent. Each customer requires from the server a generally distributed service time, also counted in slots. Customers arriving in a slot can start their service only at the beginning of the next slot [i.e. delayed access]. When upon arrival customers find the server busy, they join a queue and wait for their service. When upon arrival customers find the server idle, then one of the incoming customers (randomly chosen) starts its service at the beginning of the next slot, whereas the other incoming customers, if any, join the queue. The customers in the queue are served in the order of arrival. Arrivals have precedence over departures [i.e. late arrivals], and departures have precedence over a change of the environment.

The generating function of the joint equilibrium distribution of the number of customers in the queue, the residual service time of the customer in service, and the state of the environment is calculated. From the generating function several performance measures are deduced, like the average queue size. Also the busy period is discussed. For the special case of Bernoulli arrivals the waiting time of a customer is studied.

Delay jitter analysis

B. Oklander, M. Sidi

Abstract.– Information flow in communication networks and real-time systems grows rapidly. Notable examples for this kind of flor are Voice over IP (VoIP) and Video over IP streaming. This type of real-time traffic is sensitive to the delay jitter of the packets. We addresses the statistical characteristics of delay jitter. Analytical expressions for delay jitter and its absolute value are derived using the transformations of probability distributions (generating functions) approach. Some surprising and non-intuitive results are explored. An algorithmic methodology for the delay jitter calculations is suggested for treating cases where the generating functions approach is not applicable due to heavy tailed probability distributions. Finally, a few examples are provided to demonstrate the use of the mathematical methods presented.

Consecutive customer losses in regular and oscillating $M^X/GI/1/n$ and $GI^X/M/1/n$ systems

A. Pacheco, H. Ribeiro

Abstract.– We address the probability that k or more Consecutive Customer Losses take place during a busy period of a queue, the so called k-CCL probability, which has been subject of recent interest. This is an important

measure of the quality of service of telecommunications broadband applications that can tolerate cell loses only up to some extent without harmful degradation of the quality of service. As illustrated by A. Chydzinski [On the distribution of consecutive losses in a finite capacity queue, WSEAS Transactions on Circuits and Systems 4(3):117-124, 2005], k-CCL probabilities can not be inferred from customer blocking probabilities.

We derive efficient algorithms to compute k-CCL probabilities for busy periods of $M^X/GI/1/n$ and $GI^X/M/1/n$ systems starting with an arbitrary number of customers in the system that, essentially, reduce to solving either simple recursions or linear systems of equations. The results obtained for $M^X/GI/1/n$ systems are based on the fact that k-CCL probabilities associated to a busy period initiated by multiple customers can be expressed in terms of k-CCL probabilities associated to busy periods of systems with small or equal queue capacity and initiated by a single customer. As regards the computation of k-CCL probabilities for $GI^X/M/1/n$ systems, mixed-Poisson expected sojourn times play a major role.

We extended the study of k-CCL probabilities to $M^X/GI/1/n$ (resp., $GI^X/M/1/n$) oscillating systems, for which the service times (resp., inter-arrival times) oscillate between two distributions according to the evolution of the number of customers in the system. The results derived for regular and oscillating $M^X/GI/1/n$ and $GI^X/M/1/n$ systems are illustrated for specific sets of parameters.

New results for the finite dam models of the $M/G/1$ and the $G/M/1$ queues

D. Perry, W. Stadje, S. Zacks

Abstract.– New performance measures for the finite dam models of the $M/G/1$ and the $G/M/1$ queues are introduced. We start with a special duality existing between the $G/M/1$ finite dam and another queueing system with restricted accessibility of the $M/G/1$ type. By this duality the law of the idle period in the primal system is the law of the overflow in the dual system. The computation of the law of the overflow in the dual system enables to derive other measures such as 'number of customers' in steady state as well as 'cycle maximum' in the primal system. We also derive the law of the idle period of the $G/M/1$ finite dam with general release rule.

Waiting time distribution in a $Geo/G/1$ retrial queue

S.I. Rabia

Abstract.– This work is devoted towards obtaining the waiting time distribution in a discrete time $Geo/G/1$ retrial queue. Inter-retrial times are

assumed to follow a geometric distribution. Both persistent and impatient customers are considered. System evolution is controlled by either the late arrival scheme or the early arrival scheme. Closed form expression for the waiting time distribution is obtained in terms of two key probabilities: the probability that an arriving customer joins the server immediately upon arrival and the probability that a returning customer from the orbit is accepted for service. Special cases are considered. Numerical results are presented where the computation of the key probabilities in different settings is demonstrated.

Quantitative stability in $M/G/1//N$ queue with single server vacation: The strong stability method

F. Rahmoune, D. Aissani

Abstract.– The performance evaluation and the quality control of a broad class of real systems are based on queueing theory (systems of production, information processing systems as well as reliability systems). However, their the complexity required taking into account the idleness durations of the server. This complex structure led to study queues with vacations rather than classical queues. In such models, the server takes occasionally a vacation with random duration, which can be used to achieve one or more secondary tasks, as it can model his idleness. To mitigate the difficulties encountered in obtaining the exact and interpretable solutions for many queueing systems, the researchers resorted to the approximation methods. In this case, they are brought to replace the complex system (real), by a simpler system whose analytical results are exploitable, so the "problem of stability" appears. By the stability of systems one understands the dependence continues operating features (system) compared to its parameters. The main purpose of this paper is to use the Strong Stability Method to approximate the characteristics of the $M/G/1//N$ queue with single server vacation by those of the classical $M/G/1//N$ queue, when the rate of the vacations is sufficiently small. This last queue is simpler and more exploitable in practice. For this, we proof the stability conditions and next obtain quantitative stability estimates with an exact computation of constants. From these theoretical results, we can elaborate an application algorithm allowing to verify the approximation conditions and to provide the made numerical error.

Bayesian analysis of a queueing system with a long-tailed arrival process

P. Ramírez, R.E. Lillo, M.P. Wiper

Abstract.– Internet traffic data is characterized by some unusual statistical properties: self-similarity, long-range dependence, burstiness on multiple scales and in particular, the presence of heavy tailed variables. In this work we deal with a mixture of two-parameter Pareto distributions as an example of heavy tailed distribution and we carry out a Bayesian analysis for estimating the corresponding parameters, using the birth-death Markov chain Monte Carlo method. After that, we estimate some measures of interest related to the queueing system $k\_Par/M/1$ where k_Par denotes a mixture of k Pareto distributions. Heavy tailed variables are difficult to model in such queueing system because they lack of an analytic Laplace Stieltjes Transform. Our procedure is based on recent Laplace transform approximating results for the $Pareto/M/1$ system. Eventually, we illustrate our approach with both simulated and real data.

The minimum cross-entropy method in rare event simulations

A. Ridder, R. Rubinstein

Abstract.– In this paper we apply the minimum cross-entropy (MCE) method for estimating probabilities of rare events for random walks and for $M/G/1$ queueing systems. The MCE method is an infinite-dimensional optimisation program that minimises an entropy under constraints with respect to the original density. Its solution is used as the new density for the importance sampling simulations. We report the relationship to other techniques of finding these new densities such as large deviations, hazard rate twisting and the cross-entropy method. We discuss the prospect of obtaining in some cases better estimation results, and we prove that the MCE method leads to asymptotic optimality of the importance sampling estimator, both in the light-tailed and in the heavy-tailed case.

Queueing analysis of a degenerate buffer with general inter-arrival and service times

W. Rogiest, K. Laevens, J. Walraevens, H. Bruneel

Abstract.– We present the queueing analysis of a degenerate buffer having access to a single server. This system has a degenerate waiting room that cannot realize any given delay, but only values that are an integer multiple of a basic unit called the granularity. For infinite buffer sizes, this leads to typically longer sojourn times, and lowers the sustainable load; for finite buffer sizes, the loss probability comes to relate strongly to the granularity.

In previous work, this system was already analyzed for geometric inter-arrival and general iid service times, using a generating functions approach. Here, we extend results to the case of iid inter-arrival times with rational

probability generating function. The analysis is developed from a single system equation, that contains two non-linear effects: (i) the max operator, and (ii) the ceiling operator. We analyze both effects separately, and then combine results. We derive, e.g., an expression for the maximum tolerable arrival intensity. Further, we present heuristics for the loss rate in a finite buffer. We assess the accuracy thereof by means of a number of numerical examples, and find them to be very reliable.

On performance characteristics for queueing system with heterogeneous servers

V. Rykov, D. Efrosinin

Abstract.– This paper deals with queueing system consisting of several heterogeneous exponential servers. Some performance characteristics of such a system under the optimal control policy are calculated and compared with the same characteristics of the same model under other heuristic control policies, e.g. the Fastest Free Server (FSS) using or Random Servers Selection (RSS).

Performance analysis of an uplink scheduling algorithm for VoIP servive in IEEE 802.16d/e system

J.W. Um, B. Kim, K.J. Kim, B.D. Choi

Abstract.– This paper studies the performance of uplink scheduling algorithm for VoIP services. Uplink algorithms for real time services in IEEE 802.16d/e are UGS algorithm and rtPS algorithm. But the use of UGS algorithm for voice service with silence period causes a waste of bandwidth and the use of rtPS algorithm for voice service with silence period generates MAC overhead and unnecessary access delay. To service more efficiently, an uplink scheduling algorithm for VoIP services was used. H.W. Lee, T.S. Kwon and D.H. Cho compute the average access delay of the algorithm and show that this algorithm accepts more users than the UGS algorithm in view of mean access delay. But, in real-time applications, specially the VoIP services, it is more important to know the distribution of access delay rather than the mean of access delay. We obtain the distribution of access delay for the uplink algorithm for VoIP by using $GI/M/1$ type queue and $M/G/1$ type queue matrix analytic solution in cases that the MAC frame duration is exponential and deterministic, respectively, and obtain the maximum allowable number of users with the required delay.

Foster's theorem of critical branching processes: Unifying results for polling models in heavy traffic

R.D. van der Mei

Abstract.– We study a general class of asymmetric polling models, with general service-time and switch-over time distributions that satisfy a multi-type branching structure. This class of models encompasses a wide variety of classical polling models as special cases, including for example models with Poisson-driven simultaneous batch arrivals, with gated, exhaustive, binomial-gated, fractional-exhaustive service policies, and with cyclic and periodic server routing schemes.

The theory of multi-type branching processes is well-developed. A very powerful result that, surprisingly enough, has not received a lot of attention in the literature is Foster's Theorem, which states that critical N-dimensional multi-type branching processes converge (in some sense) to $\underline{\alpha}\Gamma$, where is $\underline{\alpha}$ is a known N-dimensional vector, and Γ is a gamma-distributed (one-dimensional) random variable with know parameters.

We explore Forster's Theorem to derive closed-form expressions for Laplace-Stieltjes Transform (LST) of the complete waiting-time distribution when the load tends to one (under proper heavy-traffic scalings), in a very general parameter setting. The results include many known heavy-traffic results as special cases, and moreover, lead to new and exact expressions for all kinds of model variants that have not been observed before.

Analysis of polling systems with two-stage gated service

R.D. van der Mei, J.A.C. Resing

Abstract.– We consider an asymmetric cyclic polling system with general service-time and switch-over time distributions and with the two-stage gated service policy at all queues. In this policy, newly incoming customers are first queued at the stage-1 buffer. When the server arrives at a queue, he closes the gate behind the customers residing in the stage-1 buffer, then serves all customers waiting in the stage-2 buffer on a First Come First Served basis, and finally moves all customers in front of the gate in the stage-1 buffer to the stage-2 buffer before moving to the next queue.

For this model, we derive, under proper heavy-traffic scaling, closed-form expressions for the Laplace-Stieltjes Transform of the distribution of the delay when the load tends to unity. The results are strikingly simple and provide new insights into the behaviour of two-stage polling systems. We provide an in-depth comparison between the two-stage gated polling model and the classical single-stage gated polling model. Finally, the results also suggest simple and fast approximations for the distribution and moments of the delay in stable polling systems. Numerical experiments demonstrate that the approximations are highly accurate for moderately and heavily loaded

systems.

This study is motivated by dynamic bandwidth allocation schemes in an Ethernet Passive Optical Network (EPON), where packets from different Optical Network Units (ONUs) share channel capacity in the upstream direction.

Ambulance allocation and performance

J. van der Wal

Abstract.– Ambulances are expensive thus one has to maximize the performance using a minimal number of ambulances. One problem is to decide about the number of ambulances and their base location. A second decision element is about which ambulance to send to an incident. Using interrelated (via overflow) loss queuing models we approximate the performance for a given allocation. Simulation is used to verify that deciding on the allocation based on these simple loss models leads to a very close to optimal allocation.

Dynamic thread assignment in layered networks

W. van der Weij, S. Bhulai, R.D. van der Mei

Abstract.– The rise of Internet and broadband communication technology have boosted the use of communication services that combine and integrate information from geographically distributed information systems. Consequently, application servers are expected to handle strongly increasing numbers of requests, while meeting strict response-time requirements. Examples of such servers are Web servers, file servers, and database management systems. In many applications, requests typically consist of a sequence of intermediate processing steps. To handle incoming requests, these application servers are typically equipped with a pool of threads where each processing step is assigned to a single thread at a time.

Motivated by these applications, we assume that each job typically consists of two consecutive steps, and study a tandem queue consisting of two multi-threading nodes. Jobs are offered to the first queue according to a Poisson process. After completion of their service at the first queue, the jobs enter the second queue. Jobs receive service only when there is a thread available at the queue, and waits otherwise. The threads of both queues share a common underlying resource in a processor sharing fashion. To optimize performance, threads can be dynamically assigned to the different steps. This raises challenging questions regarding the proper design of dynamic thread assignment policies.

For this model we derive closed-form expressions for the dynamic programming value functions, and we obtain dynamic assignment policies such

that the average response time of the jobs in the system is minimized. We prove that the dynamic assignment policies are optimal under some mild conditions.

Computing the exact loss rate in a two-class finite capacity priority queue

J. van Velthoven, B. van Houdt, C. Blondia

Abstract.– Based on matrix-analytic methods, we develop an algorithm to obtain the steady state probabilities and loss rates of a $Geo^X[K]/PH[K]/1$ two-class priority queue where each class has its own finite capacity buffer. As opposed to most prior work, we do not rely on a truncation technique that assumes one (or both) buffer(s) to be infinite, but instead deal with the two boundary problem to obtain exact results.

We reduce the computational complexity of the two boundary problem to that of a single boundary case, by recognizing that the queueing model can be captured by an existing paradigm for $M/G/1$-type Markov chains with some regenerative structure [F. Ishizaki, Stochastic Models, Vol. 18(1), pp. 25-39, 2002]. Furthermore, by observing the system only at specific time epochs, we limit the dimensions of the matrices involved in our algorithm, resulting in a decrease in the time and memory complexity needed to obtain the steady state probabilities and loss rates.

The arrival process under consideration allows batch arrivals as well as correlation between the number of arrivals within each priority class during a single time slot, there is however no correlation between the number of arrivals in consecutive time slots. The phase-type service times are assumed to depend on the customer class. We consider both the preemptive and the non-preemptive system.

After introducing the system under consideration and developing the algorithms for the preemptive and the non-preemptive queue, we include some numerical examples to demonstrate the algorithms discussed.

Discrete-time queueing systems with multiple priority classes and non-preemptive priority scheduling

B. Vinck, H. Bruneel

Abstract.– We study a discrete-time queueing system with an arbitrary number of priority classes. For each priority class, the numbers of arrivals per time slot and the service times of the customers form distinct families of independent and identically distributed random variables. The arrival processes of the different priority classes are statistically independent of one another. It is well-known that in case of (various types of) preemptive pri-

ority scheduling, the probability generating function of the waiting time of an arbitrary customer of any priority class can be obtained by modelling the time periods during which the server is busy serving higher-priority customers as server interruptions and using the equally well-known results for the waiting time of an arbitrary customer in a queueing system subject to independent server interruptions. In this contribution we assume that non-preemptive priority scheduling applies and extend the methodology so that it also applies in this more involved case. We demonstrate the usefulness of our analysis by means of a number of numerical examples that show the evolution of the expected value and standard deviation of the waiting time of an arbitrary customer of each of the classes in queueing systems with three/four priority classes and compare the result with the corresponding result in case that preemptive priority scheduling applies. The results that we derive may serve to make better decisions as regards the choice on a scheduling mechanism.

The $MAP/M/(M/G)/1$ processor-sharing queue with server breakdowns and repairs

J. Wang, Q. Li

Abstract.– This paper considers a $MAP/M/(M/G)/1$ processor-sharing queue with server breakdowns and repairs, where the lifetime of the server is exponential and the repair time is generally distributed. We apply an RG factorization approach to compute the distribution of stationary queue length and stationary distribution of the sojourn time. Also, we obtain crucial reliability indexes such as the steady-state availability, the steady-state failure frequency and the reliability function of the server. Finally, some numerical examples are presented to illustrate the impact of the arrival process, the service rate and unreliability factor on the performance of this system.

Optimal stochastic scheduling in a general tandem queue with flexible servers

J. Weichbold, K. Schiefermayr

Abstract.– We are looking for the optimal strategy in a two stage tandem queue with several flexible servers and two different types of jobs. There are holding costs per job and unit time incurring for jobs holding in the system. The goal is to assign the servers to the jobs such that the expected total holding costs resp. the average costs per unit time are minimised. We pursue to find the optimal policy for the preemptive model as well as the nonpreemptive one. For several special cases of the model, we give sufficient conditions in terms of the costs, the service rates and the number of flexible

servers, such that it is always optimal to allocate all servers only to one certain type of job.

Delay moments in polling systems

E.M.M. Winands, I.J.B.F. Adan, G.J. van Houtum

Abstract.– The present talk deals with the problem of calculating delay moments in polling systems with either exhaustive or gated service. The interest for this model is fuelled by an application in make-to-stock production environments with considerable setup times. Knowledge of the delay moments is needed to operate the system properly.

Firstly, we develop an exact mean value analysis (MVA) to compute the mean delays. The merits of MVA are in its intrinsic simplicity and its intuitively appealing derivation. As a consequence, MVA may be applied, both in an exact and approximate manner, to a large variety of models.

Secondly, we present the derivation of a novel closed-form approximation for the delay variances. Support for the accuracy of the approximation is provided by preliminary results of a numerical evaluation and by the fact that our approximation is in line with existing results for systems in heavy traffic and for systems with extremely large deterministic setup times.

Service systems with impatient customers when system is down

U. Yechiali

Abstract.– A service system suffers random breakdowns, resulting in the loss of all running and waiting sessions. When the system is down and undergoing a repair process, newly arriving customers become impatient: each individual customer activates a random-duration timer and waits for the system to return to an operative mode. If the timer expires before the system is repaired, the customer abandons the queue, never to return. We analyze this special impatience model for both the $M/M/1$ and $M/M/c$ queues and derive various Quality of Service measures: mean sojourn time of a served customer; proportion of customers served; rate of lost customers due to failures; and rate of abandonment due to impatience.

A fluid approximation for a processor sharing queue with Markov-modulated input

B. Zwart

Abstract.– Motivated by the need to develop performance models for bandwidth sharing models with time-varying arrival rates, we consider a fluid

approximation of a Processor Sharing queue with Markov-modulated input. By scaling time and the transition rates of the modulating process in an appropriate manner, we obtain a limiting stochastic fluid model. For this fluid model, of which the sample paths are not piecewise linear in general, we show how steady-state characteristics (such as the queue length and the sojourn time distribution) can be computed for hyper-exponential service times.

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- Duque de Medinacelli Street, nº 2: Phone 902 100 007, 91 429 49 51
- Mercado de Puerta de Toledo, nº 2: Phone 902 100 007, 91 364 18 76
- Barajas Airport, Terminal 1: Phone 91 305 86 56
- Chamartin Railways Station: Phone 91 315 99 76
- Madrid Puerta de Atocha: Phone 91 528 46 30

Relevant Website with useful information:

- www.softdoc.es/madrid_guide/info/
- www.munimadrid.es
- www.tourspain.es

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Museums

There is a multiple ticket called 'Paseo del Arte (Art's Walk)' for Museo del Prado, Museo Reina Sofía and Museo Thyssen-Bornemisza. The Price is 12 € and can be bought at any of the Museum's ticket counters.

Museum	Open	Closed	Price
Museo del Prado Paseo del Prado Ph: 91 3302800 Metro: Atocha (L1) or Banco de España (L2)	Tu – Sa: 9.00 to 20.00 Su: 9.00 to 20.00	Mondays	6€ Free: Sundays
Museo Reina Sofía Santa Isabel, 52 Ph: 91 7741000 Metro: Atocha (L1)	Mo – Sa: 10.00 to 21.00 Su: 10.00 to 14.30	Tuesdays	6€ Free: Sa 14.30 to 21.00 Sundays
Thyssen-Bornemisza Paseo del Prado Ph: 91 3690151 Metro: Banco de España (L2)	Tu - Su: 10.00 to 19.00	Mondays	4,80€
Monasterio de las Descalzas Reales Plaza de las Descalzas Ph: 91 454 88 00 Metro: Sol (L1, L2)	Tu – Thr, Sa: 10.30 to 12.45 16.00 to17.45 Fridays: 10.30 to 12.45 Sundays: 11.00 to13.45	Mondays	5€

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	Train	Price One way	Bus	Price One way
SEGOVIA	Regional Place: Atocha Cercanias (metro Atocha-Renfe, L1) Duration: 1h 55 Frequency departures: Each 2 hours	5,45€	**La Sepulvedana** Place: Paseo de la Florida (metro Principe Pio, L6) Duration: 1h 30 Frequency departures: Each 30 min	6,04€
TOLEDO	AVE Place: Madrid Puerta de Atocha Rail Station (metro Atocha, L1) Duration: 35 min Frequency departures: Each 2 hours	8,30€	**Continental Auto** Place: Estacion Sur (metro Mendez Alvaro, L6) Duration: 1h 15 Frequency departures: Each 30 min	4,25€
S. LORENZO DEL ESCORIAL			**Linea Interurbana 661** Place: Intercambiador de Moncloa (metro Moncloa, L6) Duration: 55 min Frequency departures: Each 15' on Working Days 1 h on Sat and Su	3,20€

Public Transport

Metro and Buses Fares:

- 1€ for a Single trip in fare zona A
- 1,50€ for a combined Metro single ticket (fare zones B1, B2, B3)
- 6,15€ for a ten-trip ticket in fare zona A ('Metrobus'). These are also valid on buses in Madrid and can be used by more than one person at a time.

Taxis:

All official taxis are painted white with a red diagonal stripe across the front doors. Taxis can be hailed by simply waving your hand. They are also available by phone:

- Radio Taxi:
  91 447 51 80
  91 405 55 00
  91 445 90 08
- Tele Taxi
  91 371 21 31
  91 371 37 11

Restaurants

Ananías, Galileo, 9 (metro Argüelles, L4, L6)

La Vaca Argentina, Pintor Rosales, 52 (metro Argüelles, L4, L6)

El Bulevar, Alberto Aguilera, 17 (metro Argüelles, L4, L6)

Las Cuevas del Duque, Princesa, 16 (close to Plaza de España)

Manolo, Princesa, 83 (metro Moncloa, L6)

El Ñeru, Bordadores, 5 (metro Sol, L1, L2)

Casa Parrondo, Trujillos, 4 y 9 (metro Santo Domingo, L2)

Hylogui, Ventura de la Vega, 3 (metro Sevilla, L2)

Asador Real, Plaza de Isabel II, 1 (metro Ópera, L2)

Lhardy, Carrera de San Jerónimo, 8 (metro Sol, L1, L2)

Da Nicola, Plaza de los Mostenses, 11 (metro Santo Domingo, L2, Callao, L5)