Vladimir M. Vishnevskiy
Konstantin E. Samouylov
Dmitry V. Kozyrev (Eds.)

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Preface

This volume contains a collection of revised selected full papers presented at the 20th International Conference on Distributed Computer and Communication Networks (DCCN2017), held in Moscow, Russia, September 25–29, 2017.

The conference constituted a continuation of the traditional international conferences of the DCCN series, which have taken place in Bulgaria (Sofia, 1995, 2005, 2006, 2008, 2009, 2014), Israel (Tel Aviv, 1996, 1997, 1999, 2001), and Russia (Moscow, 1998, 2000, 2003, 2007, 2010, 2011, 2013, 2015, 2016) in the last 20 years. The main idea of the conference is to provide a platform and forum for researchers and developers from academia and industry from various countries working in the area of theory and applications of distributed computer and communication networks, mathematical modeling, methods of control, and optimization of distributed systems, by offering them a unique opportunity to share their views as well as discuss developments and pursue collaboration in this area. The content of this volume is related to the following subjects:

1. Computer networks architecture and topology: control and management, design, optimization, routing, resource allocation
2. Analytical modeling and simulation, performance, and QoS evaluation of info-communication systems
3. Centimeter and millimeter wave wireless network technologies: local networks and 4G/5G cellular networks
4. RFID and sensor networks
5. Distributed information systems applications: Internet of Things, Big Data, Intelligent Transport Systems
6. Distributed systems and cloud computing, software-defined networks, virtualization
7. Stochastic and statistical methods in modeling of information systems
8. Queueing theory and reliability theory in computer network applications
9. Unmanned aircrafts and high-altitude platform stations (HAPS): control, communication, applications

The DCCN 2017 conference gathered 176 submissions from authors from 15 different countries. From these, 132 high-quality papers in English were accepted and presented during the conference, 39 of which were recommended by session chairs and selected by the Program Committee for the Springer proceedings.

All the papers selected for the proceedings are given in the form presented by the authors. These papers are of interest to everyone working in the field of computer and communication networks.

We thank all the authors for their interest in DCCN, the members of the Program Committee for their contributions, and the reviewers for their peer-reviewing efforts.

September 2017

Vladimir Vishnevskiy
Konstantin Samouylov

Organization

DCCN 2017 was jointly organized by the Russian Academy of Sciences (RAS), the V.A. Trapeznikov Institute of Control Sciences of RAS (ICS RAS), the Peoples' Friendship University of Russia (RUDN), the National Research Tomsk State University, and the Institute of Information and Communication Technologies of the Bulgarian Academy of Sciences (IICT BAS).

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Contents

The Survey on Markov-Modulated Arrival Processes and Their Application to the Analysis of Active Queue Management Algorithms

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Abstract. The article is devoted to the application of Markov modulated arrival processes (Markov modulated Poisson process — MMPP, Markov modulated Bernoulli process — MMBP and Markov modulated fluid flow — MMFF) models to the analysis of Active Queue Management (AQM) algorithms (Random Early Detection (RED) family, for example). The main ideas and properties of Markov modulated arrival processes (MMAP) are presented as the brief description of RED-type AQM algorithms. A review of the main results obtained with the help of MMAP processes in the analysis of AQM algorithms models is made. The authors formulated problems that also can be solved with the help of MMAP processes when analysing the systems with RED-like algorithms.

Keywords: Markov modulated arrival processes · Markov modulated Poisson process · Markov modulated Bernoulli process · Markov modulated fluid flow · Active queue management · Random Early Detection (RED)

1 Introduction

This article introduces a brief overview of Markov modulated arrival processes (Markov modulated Poisson process (MMPP), Markov modulated Bernoulli process (MMBP) (the discrete analogue of MMPP) and Markov modulated fluid flow) and their application to active queue management (AQM) algorithms.

The structure of the paper is follows: the Sect. 1 is Introduction, the Sect. 2 is a brief overview of Markov modulated arrival processes, the Sect. 3 is devoted to active queue management algorithms. The Sect. 4 introduces the review of

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the main results obtained with the help of MMAP processes in the analysis of AQM algorithms models. And the Sect. 5 — Conclusions — a brief summary of the content and purposes of the paper.

2 Markov Modulated Arrival Processes

If one wants to construct a mathematical model considering a heterogeneous character of incoming traffic (for example, burstiness) or service (failures, breakdowns, different modes of service) the point processes whose arrival (service) rates vary randomly over time are needed. These processes with heterogeneous rate arise are appliable for mathematical modelling of broadband networks, some asynchronous transfer mode (ATM) services, hybrid wireless communication channels operation, or (as will be shown later in this article) active queue management algorithms.

The first works concerning queueing models with heterogeneous arrivals and service are the works of M. Eisen and M. Tainiter [1], U. Yechiali and P. Naor [2], M.F. Neuts [3] and P. Purdue [4]. In [1,2] the same M/M/1 queueing system (with heterogeneous arrivals and service in terms of [2]) was under investigation (we should note that the term "Markovian environment" and its general form — "random environment" are still used and relevant [5–7]). The rates of arrival and service change their values due to transition of external Markov process from one state to another.

In [1,2] the similar probability generation functions (PGF) for steady-state probability distribution of two-dimensional Markov process, describing the of customers in the system, as well as mean queue length and mean waiting times were obtained. But in [1] the exact solution for PGF and mean waiting time were obtained only for infinite service rate case. In [2] the level independent customers probability distribution was derived when ratios of incoming and service rates are the same for states of governing Markov process. In [3] (the term "extraneous phase changes" is used for random environment) besides M/M/1 queueing system the general case — M/G/1 system with extraneous irreducible Markov chain with m states was considered. Two approaches to the time dependent study of this queue were presented. One generalizes the imbedded semi-Markov process obtained by considering the queue immediately following departure points; the other approach exploits the relationship between this queue and branching processes. The equilibrium condition of the queue is obtained with the help of Perron-Frobenius theory of positive matrices. As a result the recurrence relations which yield the joint distribution of the phase state at time t, the queue length, the total number served and the virtual waiting time at t were obtained.

In [4] (the term "Markovian environment") for M/M/1 system with m-state irreducible continuous time governing Markov chain the busy period, equilibrium conditions and probabilities of the system being empty (for each state of Markovian environment) were obtained with the help of analytic matrix function.

The further works are [8–13]. In [11,13] the matrix analytical method for such system investigation was suggested.

In this chapter we will study the case when the only arrival process is under Markov modulation.

Markov modulated Poisson process (MMPP). The term "Markov modulated Poisson process" was introduced by M.F. Neuts in [12].

The MMPP is the doubly stochastic Poisson process whose arrival rate is defined by an m-state irreducible Markov process. Equivalently, a Markov-modulated Poisson process can be constructed by varying the arrival rate of a Poisson process according to an m-state irreducible continuous time Markov chain which is independent of the arrival process. When the Markov chain is in state i, arrivals occur according to a Poisson process of rate λ_i. The MMPP is parameterized by the m-state continuous-time Markov chain with infinitesimal generator Q and the m Poisson arrival rates $\lambda_1, \lambda_2, \ldots, \lambda_m$.

The work [14] is an excellent survey about Markov-modulated Poisson processes and queues with Markov-modulated input and gives a lot of references for more detailed information. Also the queueing systems with MMPP are described in [15].

Markov modulated Bernoulli process (MMBP) — is a discrete time analogue of MMPP, where a time is discretized in slots (with fixed length) and the number of time slots spent by arrival process in each state of m-state irreducible Markov chain follows geometric distribution. The MMBP is defined by Bernoulli process $X = \{X_i; i = 1, 2, \ldots\}$ where each X_i is a binary random variable which arrival probability p depends on Y_n state of Markov chain (Y_n, $n = \overline{1, m}$, m — number of states of Markov chain) with transition matrix P (the elements of P define the change of Bernoulli process arrival probability) on a discrete state space E. The theory and analysis of MMBP are presented in [16,17], the estimation of MMBP parameters is given in [17]. Also the theory of MMBP may be found in [18–21] as well as examples of application.

Markov modulated fluid flow — the rate of incoming flow (represents the incoming traffic as a stream with a finite rate) is modulated by external continuous time Markov process [19]. The main difference with the previous two approaches is that Markov modulated fluid flow approach based on theory of stochastic differential equations (SDE). The fluid flow models are consider to be appropriate approximation to systems (real-life models) where the number of arrival customers is relatively large (the arrival traffic has to be heavy with system load greater than 90%).

One of the first works concerning MMFF is [23] with superposition of several incoming flows with arrival rates governed by two-state Markov chains with application to computer network analysis. The work [24] suggests for steady-state analysis of MMFF the matrix-analytical approach, based on the theory of quasi birth-death processes, for which efficient solution methods are well known [29,30]

In [25] the algorithmic approach to numerical solution of steady state distribution for queueing flow models (a buffer of infinite (finite) size) with underlying time continuous Markov is suggested.

Also worth noting is that the fluid flow modulated by diffusion process or Brownian noise is usually called as second order fluid queue [22].

The MMFF queue approach may be applied for modelling of the IEEE 802.11 protocol [29], peer-to-peer file sharing [26], optical burst switching [31], ad hoc networks [27,28], Internet of Things (IoT) [32].

3 Active Queue Management, RED-type Algorithms

According to RFC 7567 [34] active queue management (AQM) is considered as a best practice of network congestion avoidance (reducing) in Internet routers. The active queue management is a based on some rules (algorithms such as random early detection (RED) [35], Explicit Congestion Notification (ECN) [36], or controlled delay (CoDel) [33]) technique of intelligent drop of network packets inside a buffer associated with a network interface controller (NIC), when that buffer becomes full or gets close to becoming full.

We will consider only the case of RED algorithm and some its modifications. RED has the ability to absorb bursts and also is simple, robust and quite effective at reducing persistent queues.

The classic RED (random early detection or random early discard or random early drop) is a queueing discipline with two thresholds (Q_{min} and Q_{max}) and a low-pass filter to calculate the average queue size $\hat{Q}$ [35,76]:

$$\hat{Q}_{k+1} = (1 - w_q)\hat{Q}_k + w_q\hat{Q}_k, \quad k = 0, 1, 2, \dots, \tag{1}$$

where w_q, $0 < w_q < 1$ is a weight coefficient of the exponentially weighted moving-average and determines the time constant of the low-pass filter. As said in [35] RED monitors the average queue size and drops (or marks when used in conjunction with ECN) packets based on statistical probabilities $p(\hat{Q})$:

$$p(\hat{Q}) = \begin{cases} 0, \quad 0 \le \hat{Q} \le Q_{min}, \\ \dfrac{\hat{Q} - Q_{min}}{Q_{max} - Q_{min}} p_{max}, \quad Q_{min} < \hat{Q} \le Q_{max}, \\ 1, \quad \hat{Q} > Q_{max}, \end{cases} \tag{2}$$

p_{max} is the maximum level of packages to be dropped (marked or reset).

RED is more fair than tail drop when the incoming packet is dropped only if the buffer is full. Also RED does not possess a bias against bursty traffic that uses only a small portion of the bandwidth. But, as shown in [38], RED has a number of problems, one of which is that it need tuning and has a little guidance on how to set configuration parameters.

The RED modifications are well presented in [37], but we will specify some of them.

Weighted RED (WRED) [39,48] — in this algorithm different probabilities for different types of traffic with different priorities (IP precedence, DSCP) and/or queues may be defined. The modification of WRED is Distributed Weighted RED (DWRED)[40].

Adaptive RED or active RED (ARED) [41,48] — was designed in order to make RED algorithm (based on the observation of the average queue length) more or less aggressive. If the average queue length $\hat{Q}$ oscillates around Q_{min} minimum threshold then early detection considers to be aggressive. If the average queue length $\hat{Q}$ oscillates around Q_{max} threshold then early detection is being too conservative. The drop probability is changed by the algorithm according to how aggressively it senses it has been discarding traffic.

Robust RED (RRED) [42] — is proposed for TCP throughput improvement against DoS (Denial-of-Service) attacks, especially LDoS (Low-rate Denial-of-Service) attacks. The basic idea behind the RRED is to detect and filter out LDoS attack packets from incoming flows before they feed to the RED algorithm. When loss of a sent packet is detected by the source then there will be a transmit delay, so a packet which was sent within a short-range after a loss detection will be suspected to be an attacking packet. This is the basic idea of the detection algorithm of Robust RED (RRED).

EASY RED [43] — is a simpler variant of RED. the drop probability is defined not by average queue length but by instantaneous queue length. The reason is to inform the sender about congestion as soon as possible. The EASY RED parameters are the minimum threshold Q_{min} and the drop probability p_{drop}, which is a constant and used only when the instantaneous queue length is greater or equal to Q_{min}.

Stabilized RED (SRED) [44] — aims at stabilizing buffer occupation by estimating the number of active connections in order to set the drop probability as a function of the number of the active flows and of the instantaneous queue length.

Flow RED (FRED) [45,48] — uses per-active-flow accounting (based on minimum and maximum limits on the packets that a each flow may have in the queue) to impose on each incoming flow a loss rate (depends on the degree of buffer usage by a flow), it also uses a more aggressive drop against the flows that violates the maximum bound. The state information about active connections also needs to be maintained in the routers

Balanced RED (BRED) [46,48] — is proposed to regulate the bandwidth of a flow also by doing per-active-flow accounting for the buffer, similar to FRED but with a different approach: in BRED, two variables (the measures of the packet number for one flow in the buffer and the packet number accepted from this flow since the previous packet dropping) for each flow having packets in the buffer are maintained, which are. As a result the decision of packet drop or acceptance is based on before mentioned two flow state variables.

Dynamic RED (DRED) [47] — is proposed to discard packets with a load dependent probability. The drop probability is updated by employing an integral controller (the input of the controller is the difference between the average queue length and the target buffer level, the output is the drop probability).

The more information about RED and its modifications (Gentle RED (GRED), RED with In and Out (RIO), WRED with thresholds (WRT), Exponential RED (EXPRED), Double Slope RED (DSRED), Random Early Dynamic

Detection (REDD)), as other AQM algorithms (Random Exponential Marking (REM), Blue [53] and stochastic fair Blue (SFB), Adaptive virtual queue algorithm) is available at Sally Floyd webpage [49] (up to 2008 year), or in [48,50–52], new approaches to AQM [54].

4 The Application of Markov Modulated Arrival Processes Theory to the Active Queue Management

In this part the brief overview of articles with Markov modulated arrival processes application (since Internet traffic is known to be bursty and exhibits Long Range Dependence (LRD) characteristic, Poisson and Bernoulli processes failed to model bursty and correlated traffic in adequate manner) to AQM algorithms will be presented.

Markov modulated Poisson process approach. Markov Modulated Poisson Process (MMPP) is used for bursty and correlated traffic modelling due to the simplicity of its mathematical model [55,57,59,60]. It was shown that superposition of MMPP can be used to model variable packet traffic with Long Range Dependence [55,57]. In [55] superpositions of two-state Markovian sources is suggested as a very versatile tool for the modelling of variable packet traffic with Long Range Dependence (LRD). The article [57] gives a short survey of Internet traffic modelling and introduces MMPP model for traffic with LRD. One of the most recent works on this item is [58], where the queueing behavior of the Internet router employing priority based partial buffer sharing mechanism under synchronous self-similar traffic input is investigated with Markov modulated Poisson process modelling of incoming traffic. The authors consider the output port of the router as a multi-server queueing system with deterministic service times (service time is a packet length) — $MMPP/D/c/K$ (according to the Kendalls notation), where K is the number of wavelength channels for each fiber line of the router (which consists of N input fiber lines and N output fiber lines), c – the size of a wavelength converter pool ($0 \leq c \leq K$), dedicated to each output fiber line. By using the matrix-geometric methods and approximate Markovian model authors computed high priority and low priority packet loss probabilities, and mean length of non-critical and critical periods against the system parameters and traffic parameters.

In [56] the MMPP model was applied for modelling of exogenous stream, representing the superposition of all incoming UDP connections into a queue, for the problem of the stability and performance analysis of a system involving several TCP connections (TCP Tahoe and the TCP Reno) passing through a tandem of RED controlled queues (each of which has an incoming exogenous stream) was studied. As results the conditions for stability of the system and closed form expressions for the throughput of the TCP connections also as the mean sojourn times of the TCP and the exogenous streams were obtained.

In [61] the problem of service rate control (the optimal service rate) was considered ans it was shown that the optimal service rate was nondecreasing in the number of customers in the system and higher congestion levels warrant higher service rates. Also the authors shown that the optimal service rate is not necessarily monotone in the current arrival rate. The full version of this work is [62].

In [59] the queueing model for GRED-I (Gentle RED with instantaneous queue length) algorithm with different classes of bursty traffic is investigated. The aggregate traffic in proposed queueing model is defined by the superposition of 2-state MMPP. For each traffic class two individual thresholds are assigned in order to differentially control traffic injection rate. In [60] the analytical model for priority-based AQM with heterogeneous bursty traffic (Markov-Modulated Poisson Process) and non-bursty traffic (Poisson process) is discussed. The each traffic class has individual thresholds. For traffic injection rate control the Preemptive Resume (PR) priority scheduling mechanism is adopted to control. The expressions of the aggregate and marginal performance characteristics of the priority-based AQM system are obtained.

Even MMPP approach is regarded to be less complex, some scientists [68] consider MMPP models to disagree with the digitalised communication world, so Markov modulated Bernoulli process approach is more appropriate.

Markov modulated Bernoulli process approach. Internet traffic consists of traffic flows from various network applications and these flows may be classified at edge routers into different traffic classes in order to enable differentiated service to be applied (based on the traffic classes defined by router).

The methodology of bursty traffic sources modelling by the Markov Modulated Bernoulli Process with two states (MMBP-2) is presented in [63]. The proposed technique can be extended to an MMBP with m states. In this article the following queueing models were under study: the infinite buffer system with MMBP-2 batch arrivals, the infinite buffer system with a group of two identical MMBP-2 sources, finite buffer system with two MMBP-2 sources with different parameters. For all cases the queue length distribution in the framework of Markov theory was obtained.

In works [64–68] the Markov modulated Bernoulli process is applied to AQM modelling and analysis. The [64–67] consider analytical model proposed for a single MMBP-2 arrival process. In [64] a discrete-time stochastic queueing model for the performance analysis of congestion control mechanism based on Random Early Detection (RED) methodology with bursty and correlated traffic by using a two-state Markov-Modulated Bernoulli arrival process (MMBP-2) as the traffic source was presented. Two traffic classes were modelled by two-dimensional discrete-time Markov chain (each Markov chain dimension corresponds to a traffic class with its own RED parameters). The authors computed such performance characteristics as the mean system occupancy and mean packet delay, system throughput and the probability of packet loss (functions of the thresholds and maximum drop probability). In [65,66] the same model as in [64] but for multiple-class traffic with short range dependent traffic characteristics was considered. The results of this work — the analytical expressions for various performance metrics, the demonstration of the effect of input parameters on derived performance metrics.

Since the analytical models proposed in [64–67] were not able to represent traffic flows with different characteristics and precedence, the model based on superposition of multiple MMBP-2 sources (for aggregated Internet traffic from multiple traffic classes) for RED and WRED queue management schemes performance evaluation was introduced in [68].

Markov modulated fluid flow approach. It is commonly used to apply fluid models to AQM analysis, for example for the first time the fluid models for TCP and RED analysis were applied in [69–71]. In [69] the simple fluid analysis of TCP and other TCP-like congestion control mechanism was described. The authors modelled the window size behaviour as a Poisson Counter driven Stochastic Differential Equation and performed analysis. In [70] jump process driven Stochastic Differential Equations to model the interactions of a set of TCP flows and Active Queue Management routers in a network setting were used. As an application, the system with RED as the AQM policy was modelled and solved. By using fluid flow approach the role played by the RED configuration parameters on the behaviour of the algorithm in a network was explained. And in [71] the authors designed an AQM control system using the random early detection (RED) scheme by relating its free parameters such as the low-pass filter break point and loss probability profile to the network parameters. The guidelines for designing linearly stable systems subject to network parameters like propagation delay and load level were presented.

The fluid flow model approach for AQM analysis was also used in [72,73] and developed for Wiener fluid process governed by Poisson process (Poisson counter). The method of stochastization (randomisation) of one-step processes (birth-death processes) [74–79] is proposed for active queue management analysis in before mentioned model. In [75] the methodology of combinatorial and operator approaches of the method of one-step processes stochastization (randomisation) to RED modelling is introduced and discussed.

In [80] the wireless TCP fluid model (WTFM) (based on cross layers) was proposed for stability analysis of wireless network. The active queue management, abnormality of wireless channels and packets collisions were taken into consideration. According to obtained in [80] results the proposed WTFM model performs better than other schemes (the classical fluid model and the convex optimisation model) in comprehensive aspects on capturing the characteristic of the wireless network and computing complexity.

5 Conclusions

The brief history and the theory of Markov modulated arrival process and their applications to the modelling and analysis of RED-like active queue management algorithms were presented in the article.

The authors consider that not only Markov modulated arrival processes may be applied to the AQM modelling and analysis (as shown before), but the queueing systems with renovation (general renovation) [81–86] may be also applied (as shown, for example, in [87]) coupled with Markov modulated arrival or service processes.

Authors plan to expand the queueing model of RED algorithm with batch arrivals (it was considered in [88]) by Markov modulated arrival and service processes.

At the end, it is worthy of mention that the other approach to the analysis of behaviour of networks with burst traffic (for overload (congestion) control) may be applied — the method based on hysteretic thresholds load control [89,90].

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