Research Statement

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1 Research Interests

My research interests lie on the field of Applied Probability, Stochastic Processes and Queueing Theory. More precisely, my work deals with the modeling and analysis of stochastic models inspired by real world applications arising among others in communication systems, computer networks, manufacturing and energy aware systems.

My research is motivated by the idea that proper modeling and analysis can improve the design and performance of any system where the flow of information is not deterministic but random. My ambition is to provide exact statements about systems affected by random events. The goal of my research is to identify and isolate in a real system the components that mainly influence its performance, and then develop models of these components in order to provide analytic results characterizing the impact of design decisions on the system as a whole.

In this direction, I have strived to build a solid background based on techniques used in the analysis of stochastic processes, such as: Transform methods (generating functions, Laplace transform), Complex function methods (theory of boundary value problems), and special techniques (matrix analytic methods, compensation method, power-series algorithm, regenerative approach, fluid limits technique, heavy traffic analysis, power series approximation). In the following, I briefly describe my research activity on specific areas.

2 Research Topics

2.1 Retrial queues

Retrial queues characterize situations where arriving customers who find all servers busy are obliged to leave the service area and return after a random amount of time. Applications of such models are found in the modeling of telecommunications and manufacturing systems.

Since 2008, I have published over of twenty papers in prestigious international journals and conferences (see detailed cv; e.g. *Queueing Systems, European Journal of Operations Research, Performance Evaluation, Operations Research Letters, Annals of Operations Research, Probability in the Engineering and Informational Sciences, Computers and Operations Research, Applied Mathematical Modelling, Applied Mathematics and Computation, Computers & Industrial Engineering, The Computer Journal, Stochastic Models, LNCS, APS INFORMS 2015, ASMTA 2015, 2016, 2017, WRQ 2008, 2016*)). In most of these works, I used *embedded Markov chain approach and supplementary variable method*, along with *generating function approach* to study the stationary behaviour of the system. Moreover, I used results from the *semi-regenerative processes* to study the stability conditions. I also developed a *special approach* to obtain basic performance metrics for multiclass retrial systems under the classical retrial policy.

Recently, I introduced for the first time in the related literature, the concept of processor sharing service discipline in retrial queues. Such a framework has potential applications in bandwidth sharing in internet networks. Moreover, I also introduced in the related literature, the use of *Riemann(-Hilbert) boundary value theory* to analyze two-class retrial queues, with coupled retrial rates (i.e., the retrial rate of an orbit depends on the state of the other orbit), with both exponentially and arbitrarily distributed service times. Furthermore, I contributed on the analysis of two-class retrial systems with coupled orbit queues by using an elegant and computationally efficient *Power Series approximation method*. There, I expressed the probability generating functions of the stationary joint queue length distribution as power series expansions of a system parameter, without calling for advanced concepts such as Riemann-Hilbert boundary value problems. I also recently contributed in the derivation of the stability conditions of a multi-class retrial system with coupled orbit queues using the *regenerative method*. In such systems, the retrial rate of an orbit queue depends on the state of the whole network. Quite recently, I have introduced the concept of the join the shortest queue policy in the retrial setting. Using the *compensation* method we obtained the stationary joint orbit queue length distribution for either server state as a series of linear combinations of product forms. Some asymptotic results on the stationary distribution are also derived. This work was both methodological and application oriented. This is due to the fact that the resulting process is a Markov modulated random walk in the quarter plane. Applications are found in the modelling of cooperative networks and in layered queueing models. My current activity on this topic relies on investigating rare events and other asymptotic results for large scale networks (heavy traffic, large deviation approach), as well as investigating the possibility of extending existing methods to analyse Markov modulated join the shortest orbit queue systems with retrials.

I am currently working in the context of multi-class retrial systems, with particular interest on the investigation of stability conditions in systems with state-dependent retrial rates. Another field of interest is the investigation of the stability conditions along with the stationary analysis of sophisticated load-balancing schemes in multi-class retrial systems. I also currently working on the stationary analysis of a novel multiclass retrial system with potential applications in the modelling of software define networks. Motivated by the customers' behavior in service systems, we also plan to develop models where arrivals depend on the last system event.

2.2 Queueing models for energy management

I have also worked on the development of queueing systems for modeling smart, self-organized, energy aware communication systems. My experience as a postdoctoral researcher at Imperial College, London, UK (FP7 Project (P24736 EESD) FIT4Green, October 2011-June 2012), where I worked on the energy management of data centers inherits me many ideas regarding the modeling of such systems.

Indeed, it helps me to write two small research projects. The first one was awarded with an ERCIM "Alain Bensoussan" fellowship (co-funded by Marie Curie actions) for INRIA, Sophia Antipolis, France (5/14-7/14), and the second one with a postdoctoral scholarship by the Research Committee of AUTH (2013), for the Department of Mathematics, Aristotle University of Thessaloniki (AUTH). The outcome of this research activity was five publications in prestigious international journals and conferences (*Performance Evaluation, Annals of Operations Research, The Computer Journal, EPEW 2015, ISCIS 2014*), and 1 technical report.

By exploiting my knowledge on analytical methods, I currently keep on working on this field by focusing on energy harvesting networks with energy cooperation capabilities, with ultimate goal to optimize the system performance by improving its energy efficiency under certain performance criteria.

2.3 Game-theoretical aspects of wireless markets

As a postdoctoral researcher at FORTH, ICS, Greece (9/13-7/14), I participated in a project funded by the General Secretariat for Research and Technology, entitled "Developing the Foundations for Modeling and Analysis of Spectrum Markets (CoRLAB)". The program dealt with game theoretical analysis of wireless markets.

The main goal was the development of a modeling framework for analysing such markets using *network economics, game theory, and queueing networks.* Such a framework, models the service selection of users, and the competition/coalition among providers. Moreover, it develops algorithms to analytically compute the *Nash equilibriums* under the presence of discontinuities in the derivatives of the utility functions of providers.

My contribution there was to develop a method to enhance the computational efficiency of large-scale wireless markets, by introducing a *general queueing network* to describe a wireless network of different service providers, and developed a *network aggregation methodology* based on the *Norton's theorem.* This approach allows the construction of equivalent networks for a specific region of interest, by including all the details of the rest of the network to single macro-node. The derived algorithm was demonstrated in the context of capacity planning. The outcome of our work was one journal paper in the prestigious *IEEE Transactions on Mobile Computing.*

2.4 Analysis of random-access networks using complex analytic & special methods

Quite recently, I focused on the development and performance analysis of of novel random-access schemes in wireless networks. In particular, I developed novel slotted-time queueing systems to investigate the delay in cooperative random-access wireless networks. However, due to the interdependence among queues at relays, the characterization of the delay even in small random-access networks is a rather difficult task. We have contributed in this direction and investigated the delay in such networks by using the *generating function approach.* The analysis led to a functional equation, the solution of which is derived with the aid of the theory of *Riemann-Hilbert boundary value problems.* I also studied the throughput, as well as stability conditions using the concept of *stochastic dominant systems*, which is based on whether the system of interest is stochastically comparable to a simpler system that is easier to derive the stability conditions. Quite recently, we introduced the concept of signals in random access networks to cope with virus attacks as well as to improve load balancing. Delay analysis was performed interms of a solution of a non-homogeneous *Riemann boundary value problem.* The outcome of this research activity more than ten papers, published in prestigious international journals and conferences such as *IEEE Transactions on Wireless Communications, Ad Hoc Networks, Queueing Systems, Performance Evaluation, Probability in the Engineering and Informational Sciences, Stochastic Networks meeting 2018, LNCS, ITC 2018, ICC 2018.*

We implemented other special methods such as *compensation method* and *power series algorithm.* In particular, we first focused on the stationary analysis of the *join the shortest queue policy in a slotted ALOHA network* (under review, preprint available upon request). The two-dimensional Markov chain that describes the system is a non-homogeneous two-dimensional random walk. Our theoretical contribution relies on the fact that we extended the class of random walks in the quarter plane, in which *compensation method* is applied, and we provided an extensive numerical comparison of these methods by discussing which one performs better in terms of accuracy and computation time. We also provided details on how study the delay in terms of a solution of a *Riemann-Hilbert boundary value problem.* By application point of view, this work is the first in the related literature that deal with the delay analysis of an ALOHA network under this *special routing protocol.*

Quite recently, we focused on a random access Internet of Things IoT wireless network assisted by two aggregators collecting information from two disjoint groups of sensors. We characterize the throughput performance of the IoT network and we obtain the stability conditions for the queues at the aggregators. We apply the theory of boundary value problems to analyze the delay performance. Our results show that the presence of the aggregators provides significant gains in the IoT network performance, in addition, we provide useful insights regarding the scalability of the IoT network.

The emergence of these networks provides several other open technological and mathematical challenges, that we aim to investigate in the future. Our aim is to further investigate this area, and use our work as a building block in order to study the delay of random-access networks with arbitrary number of users, as well as to perform the heavy traffic analysis.

2.5 Queues and random walks in the quarter plane

A major part in my recent research relies on the study of two-dimensional random walks in the positive quadrant. Each step (to a neighboring site) occurs with a certain probability, where different probabilities may be taken for the interior of the state space and the boundaries. The generating function $Q(x,y)$ of the stationary distribution of such random walks satisfies $K(x,y) = A(x,y)Q(x,0) + B(x,y)Q(0,y) + C(x,y)Q(0,0)$, where the functions K and A, B, C are known functions in x and y. Finding $Q(x,y)$ through functional equations is the universal problem for random walks in the quarter plane. Such functional equations can be solved using the theory of boundary value problems.

Quite recently, I extend the use of the *theory of boundary value problems* to the analysis of specific Markov-modulated two-dimensional random walks in the quarter plane. In such a case, the transition rates among the states are affected by the state of a background Markov process. Additionally, in the same work I used the *power series approximation* method as an alternative way to investigate its stationary behaviour. The results of this work are published in *Annals of Operations Research.*

Quite recently, I also contribute to the stationary analysis of partially homogeneous random walks in the quarter plane. Such random walks are characterized by the fact that their one step transition probabilities are functions of the their state up to a specific state. Their stationary behaviour is investigate in terms of the solution of a *Riemann-(Hilbert) boundary value problem, a system of two matrix equations, and a linear system of equations.* Applications of these random walks are found in the modelling of flow level performance in wireless networks (through a limited discrete time generalized processor sharing queue), as well as in queue-based random access networks. This work is currently under minor review in the prestigious journal of *Queueing Systems.*

Currently, I also keep on working on the stationary, as well as on tail asymptotic behaviour of Markov-modulated multidimensional random walks. My specific interest relies first on the two-dimensional case, since much work must be done even in this small dimension. Based on our work there, we aim to provide results on the larger dimensions.

2.6 Performance analysis of caching systems

In computing, a cache is a hardware or software component that stores data so future requests for that data can be served faster; the data stored in a cache might be the result of an earlier computation, or the duplicate of data stored elsewhere. My research activity in this field results in a journal publication in the distinguished *IEEE Access Journal* (available upon request). In that work, we focused on the delay and throughput performance under the effect of bursty traffic, and random availability of caching helpers in a wireless caching system.

This research field is quite new, and has caught my attention since the ubiquitous internet connection as well as the growth of real-time applications reveal new challenging research questions.

2.7 General Information

My short-term research goals are to further develop the areas I have already worked and, more importantly, to acquainted to new areas of research regarding stochastic operations research and stochastic modelling. In this direction, I co-organized two international symposiums SAMMA 2016, 2017 that dealt with recent trends on the analysis of stochastic systems.

I also served as a program committee member (TPC) for the ASMTA 2016, 2017 conferences on stochastic modelling techniques and applications, for the ESM 2018 (European Simulation and Modelling) Conference, October 24-26, 2018, Ghent University, Ghent, Belgium. I will be a TPC chair in the forthcoming ASMTA 2021, and I organise two sessions in the forthcoming IWAP (International Workshop in Applied Probability) 2022 (Thessaloniki, June 2022), and in the EURO 2021 (Athens, 11-14 July 2021) conference on operations research. Since 2014, I also serve as a program committee member for the biannual international workshop organized especially for retrial queues. Furthermore, I am a regular reviewer for more than 25 international journals (see detailed cv), and serve as a reviewer of project proposals for the *Flemish Research Foundation (FWO)*, Belgium, and *Hellenic Foundation for Research and Innovation (HFRI)*, Greece, (Research Projects for Postdoctoral Researchers). To conclude, I am also member of the *Euro Working Group on Stochastic Modeling*, and served as a professional member (Member number 6271326) of the *Association for Computing Machinery (ACM)* in 2017.

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