Final report

K101150

Network level traffic analysis of infocommunication systems

(2012-2016)

The active market competition on the field of infocommunication and the increasing dependencies on infocommunication related services continuously raise hot research topics for the research of various aspects of the field. Large number of industrial and academic research groups work on the solutions of these research challenges all over the world. The K101150 research project achieved research results on some specific subjects of this large research field according to the following chronological list. The set of results summarized below exceeds our preliminary expectations on the success of the research project reported in the project proposal.

2012

In [1] we were investigating the ways to improve the efficiency (in terms of dynamic traffic parameters, e.g. autocorrelation) of 2 step MAP (Markov arrival process, a point process with a modulating Markov chain) fitting methods by the optimization of the PH (phase type distribution, time to absorption in Markov chain with an absorbing state) representation obtained during the first step of the procedure. We have shown that the efficiency of the PH representation optimization method depends very much on the properties of the applied PH fitting procedure. There are cases when the proposed method improves the obtained MAP significantly and there are cases, when it does not have tangible effect.

In [2] and [9] we studied the representation of MAPs and (the more general non-Markovian) RAPs (rational arrival processes) with different sizes. We also investigated the model construction ([2]) and transformation ([9]) processes which ensures that the combined models with MAP and RAP ingredients is valid stochastic process.

The use of PH and ME (matrix exponentially, the non-Markovian generalization of PH) distributed random variables in applied simulation models largely depends on the computational complexity of generating such pseudo random variates. We have proposed efficient methods for generating PH [3] and ME [4] distributed pseudo random numbers. In both cases the first step of the procedure is the transformation of the input representation into a standard efficient form.

Efficient numerical analysis procedure is proposed also in [5]. The most difficult step of the analysis of the M/G/1 and G/M/1 type Markov chains is the computation of the characteristic matrix of the model. The proposed procedure enhances the computational complexity of the Newton iteration based method, when the matrices describing the transition structure has limited rank.

In the standard analysis of finite buffer fluid models the case of unit load is excluded, because the solution of the involved linear system of equation gets to be non-unique. In [6] and [13] we extended the analysis of finite buffer fluid models with the case of unit load by an accurate evaluation of coinciding eigenvalues and associated eigenvectors.

[11] is the result of a long book publication project in which we summarized the most important basics of our field in a monograph for graduate and postgraduate students.

2013

The main problem of fitting Markovian traffic models is the non-unique representation of those models. To avoid the optimization of parameters in the space of a redundant set of parameters it is essential to find a unique representation of various model classes of Markovian traffic models. Such unique representations are referred to as canonical representation. We have defined such canonical forms for discrete time Markov chain modulated low order traffic models [10], [7].

An additional research direction of Markovian traffic models is the research of more complex Markov modulated stochastic models like the transient traffic models and the branching processes [12]. The main properties of these processes and the applicability of analysis techniques available for simpler Markovian traffic models are still to study.

A rather general open research problem of the field is the existence of Markovian representation of stochastic processes characterized by (non-Markovian) matrix representations. Necessary conditions are known, but convenient necessary and sufficient conditions are remote research goals. We proposed a numerical method to find a Markovian representation [8]. The main advantage of the proposed method is the fact that Markovian representations of larger size than the original non-Markovian one is also possible to compute.

2014

The set of research results published in 2014 can be classified according to the following main groups.

1.) Analysis of fluid vacation models:
In this research line our aim is to develop a set of analytical results which allows the numerical analysis of fluid vacation and polling models. A set of analysis results are available for vacation and polling models with discrete customers. The extension of those results to fluid queues requires the application of a completely different analytical treatment. The initial results we obtained for vacation models [25], [26] (which are special polling models with a single station) are promising for further generalizations, because we established some essential elements of the required methodology.

2.) Waiting time analysis of queues:
The essential problem of waiting time analysis of queues with Markov modulated input and output processes is the computational complexity of the analysis, because the cardinality of the matrixes used in the evaluation is the square of the state space. In case of independent Markov modulated input and output processes we have recognized an interesting commutativity of the required matrices which allowed a much simpler computation of the waiting time, where the cardinality of the matrixes used in the evaluation is identical with size of the state space [17], [18] and its conference version [19].

3.) Properties of PH distributions:
The facts that the Markov chain based matrix-vector representation of PH distributions is not unique and that the border of the set of PH distributions is not known make the analysis of those distributions very difficult. We obtained an efficient numerical procedure to investigate the problem if a vector-matrix pair corresponds to a PH distribution, which makes the numerical analysis of the border of the set of PH distributions possible [23]. Additionally we proposed a heuristic numerical procedure for compact representation of PH distributions [21], which is an initial step towards the minimal representation of PH distributions.

[15] presents an essentially empirical study in which we investigated the advantages of canonical from based fitting compared to the previously available fitting procedures. The study verified the importance of the use of canonical forms.

A further optimized PH distributed pseudo random number generation method has been proposed in [20], where a heuristic (or exhaustive) search of optimal representation is applied in advance to the actual random number generation.

4.) Mean field limit:
The overall behaviour of a large number of dependent, identical Markovian stochastic models whose behaviour depends only on the distribution of the rest of the population can be described by an ordinary differential equation as the size of the population tends to infinity. This property is referred to as mean field limit. In the case when the individual models are non-Markovian due to the presence of a non-exponentially distributed activity time the mean field limit is suspected for some time, but was not proved. In [24] we proved the mean field limit for a particular case of non-Markovian components.

5.) Applications:
The set of results published in [22], [14], [16] cover a wide range of application fields from radio propagation in modern mobile telecommunication networks [16] to the modeling of intelligent car parking systems [22]. The MAP/MAP/n queue in [14] is a queueing model to describe a cloud computing system where the tasks have to be assigned to one of the servers such that the overall response time is minimal.

2015

The efficiency of data transmission in wireless communication depends on the knowledge of the receiver on the channel state. In practice this information is obtained through known pilot signals. The distribution of the power budget among the pilot and the data signals is investigated in [27], [28], and optimal pilot power assignment is proposed under different assumptions on the receiver behavior.

Along the research line initiated in [25] and [26], an important modeling restriction (during the service period the buffer content is monotone decreasing) has been relaxed in [32]. The relaxation of this modeling assumption required the introduction of a completely new modeling methodology (instead of transform domain operators we used the matrix analytic approach for the analysis of the fluid buffer during the service period).

It is known for a long time that the queue length distribution and the sojourn time of QBD queues are matrix-geometric of order-N and matrix-exponential of order $N^{\wedge 2}$, respectively. In [30] we proved that, allowing matrix-geometrically distributed batch arrivals and services, the same results hold, thus the representations of these performance measures have the same sizes and can be computed with the same computational complexity.

[29] presents a new approach for the analysis of priority queues that are used frequently to model telecommunication, logistic, or healthcare systems. When the arrival process is given by a MMAP and the service times are PH distributed, this new algorithm is able to provide the moments and the distributions of the queue length and the sojourn time several orders of magnitudes faster than alternative methods, without any numerical issues.

By using the method described in [31] it is possible to calculate the squared distance between two Markovian arrival processes in an efficient way. Many optimization procedures (like fitting methods) rely on the iterative evaluation of this distance that can benefit from this result by extending the limits of the computable set of models.

Queueing models usually assume independent arrival and service processes. The case when a common background process modulates the two, resulting in dependent arrival and service processes, are hard to analyze in general. [33] presents an analysis method for the general class of vacation models with dependent Markov modulated arrival and service processes. Several famous previously obtain research results can be obtained as a special case of this general model.

While the set of order 3 continuous PH distributions has a reasonable simple canonical form with 3 different structural cases, the set of order 3 discrete PH distributions has a more complex structure. Based on the eigenvalue structure of the generator there are four cases (such that the full complexity of the continuous case is covered by one of these four cases). The canonical representations of the 4 different cases are presented in [34], where the proof of the completeness is still missing for one of the subclasses.

The canonical representation of non-stationary order 2 MAPs is presented in [37]. In this case the canonical representation is the same as for the stationary order 2 MAPs, and the paper provides the proof of the completeness and uniqueness.

The existence of PH representation of a given set of distributions with matrix exponential distribution function is proved for a long time, but this theoretical proof does not shed light on any computable property (e.g. how expensive is to approach the limits of the set). In [35] we proposed a constructive proof which provides answers also for computable properties.

The optimal task delegation in peer-to-peer computing platforms is investigated in [36]. The use of peer-to-peer computing platforms might not be dominant in the future, but somewhat similar optimization problems arise in cloud computing systems as well.

Transform domain results of memoriless queueing models are hard to generalize for similar models with Markov modulated environments essentially because the matrices describing the Markov modulated environment do not commute. In [38] we presented a procedure for the analysis of such systems, where the transform functions are replaced by relations of infinite summations.

Concluding remarks

In the project plan we focused on several actively elaborated research fields of infocommunication systems. During the project we continuously obtained research results which were published in high level international journals and conference proceedings. The obtain results covers and partially exceeds the research plans. We found the publication level of the research results sufficiently high. Apart of the already published research results listed in this project report there are pending publications associated with this research project. Some of the early publications were cited by independent authors.

The research project efficiently supported the research of PHD students as well. Illés Horváth defended his PHD thesis in 2015, which contained the results published in [24] and [35]. András Mészáros also got close to completing his PHD thesis which is going to be based on the results he obtained in the frame of this research project, e.g., in [7], [14], [37].

References

The list of references is taken from the official web site of the project report and is attached below for completeness.

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		Szakmai jelentés:	
Vezető kutató: Telek Miklós	Kutatóhely: Hálózati Rendszerek és Szolgáltatások Tanszék (Budapesti Műszaki és Gazdaságtudományi Egyetem)		
Zsűri: IVM	Kezdet: 2012. 02. 01	Teljes kutatási időszak: 2012-02-01 - 2016-01-31	Főkönyviszám: 71203	Nyomtatás: 2016. 03. 04.

NEM VÉGLEGESÍTETT VÁLTOZAT!!!

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