Summary of the scientific contributions in the publications presented as a cumulative habilitation thesis

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Among the publications presented at the present competition, 8 represent a cumulative habilitation thesis. Their volume (equivalent to 116 standard pages) exceeds the minimum required volume of 100 standard pages of 1800 symbols per page which qualifies the work as a monography. In this summary, these publications are numbered from 1 to 8, while all other sources are cited using the Harvard reference system.

The thematic area in which the publications fall is "Modelling of service systems". The scientific contributions can be presented as a monography with the title

New Models of Service Systems

1. Introduction

Various approaches to the conceptual modelling of service systems exist. In the conceptual modelling of complex systems such as the overall telecommunication system in [Poryazov, Saranova, 2012], for the purpose of the analytical modelling, the choice of a suitable conceptual model is of high importance. With a view to achieve maximum conceptual clarity and simplicity of the derivation of mathematical models from the conceptual ones, it is necessary to compare various approaches such as the methods for conceptual modelling [Robinson et al, 2011], teletraffic theory [Iversen, 2010], the modern methods for network planning [Larsson, 2014], the apparatus of the Generalized Nets (GNs) theory [Atanassov, 2007]. The conceptual models of telecommunication system and its environment make use of notions from the service systems theory. However, the latest results of the theory of the GNs, which can have certain advantages in some cases, are rarely used. With a view to compare GNs models with models based on service systems theory, it is necessary to construct GNs representations of the base and often used elements of service systems theory. If necessary, new extensions of the ordinary GNs can be proposed, similar to the already existing ones in the conceptual modelling of telecommunication networks with Quality of Service (QoS) guarantees [Andonov, 2018] – Generalized Nets with Characteristics of the Places (GNCP) [Andonov, 2013].

The duration of staying of the requests in the queue has an impact on the Quality of Experience (QoE). Therefore, the inclusion of queuing systems in the models of overall telecommunication systems is important. An overview of the literature shows that in the models of overall telecommunication systems with QoS guarantees, queuing systems are practically not considered because their inclusion leads to increase of the complexity of the model. This makes the construction and comparison of various conceptual models of queuing systems a necessary step. This, in turn, would allow for the most suitable model for the purpose of the analytical modelling to be determined. The first GN models of queuing systems are described in [Tomov et al, 2018], while in [Poryazov et al, 2018] four conceptual models of queuing systems are compared. The values of the parameters of the queuing system, in the context of overall telecommunication system, can be determined with the methods described in [Mirchev, 2015], [Schneps, 1979]. However, the impact of the feedback on the system is not taken into account.

At present, the models for QoS prediction, on which significantly depends the perceived quality (QoE), usually reduce the concept of quality of telecommunication service at least in two ways:

- QoS is reduced to determining a certain number of network parameters such as the degree of packets and requests losses, frequency range, traffic capacity, transmission lag, jitter etc., which can be easily measured but have limited importance when it comes to subjective perception of the quality by the end user.

- Quantitative characteristics of the interaction between the QoS delivered and the users' behavior are modelled extremely rarely.

This leads to a need for construction and use of models of overall telecommunication systems, including parameters characterizing the users' behavior (for example reactions in case of unsuccessful request, depending on the reason for failure).

Generally, the models of overall telecommunication systems consist of users, terminals, telecommunication network and telecommunication service provider. The users are predominantly people, but can be also devices or programs [ITU-T Q.1300]. The terminals include users equipment which can be a whole network.

The main method for QoS guaranteeing in modern telecommunication networks is the resource reservation (virtual channels; bandwidth service places, etc.) in order to provide quality of service of the traffic with high priority (class 0 – in real time, sensitive to jitter, with high interactivity – i.e., video conferences). The traffic with lower priority uses the resources dynamically freed by the high priority traffic. For this reason, we consider telecommunication systems with virtual channel switching, including users' behavior. Telecommunication networks with generalized number of virtual channels are studied because the QoS in the modern systems is restricted predominantly by the access networks (for example in wireless interface), because the transit networks can be dimensioned relatively easy.

Models of the connection between QoS and QoE exist which are necessary for the prediction of the perceived quality in telecommunication system with QoS guarantees, together with the links of the users of the telecommunication services (psychological, physiological, economical, social etc.) to the environment (the context) [Reichl et al, 2015-01, 2015-02]. They have impact on the QoE and are dependent on the perceived productivity of the telecommunication system. On the basis of the chosen indicators for QoS prediction, oriented towards the users, it is necessary to analyze the published dependencies in [Tsiaras et al, 2015] and others, which use the Weber-Fechner law [Reichl et al, 2010] and monotonic function between the values of QoS and QoE. The main hypothesis states that for the prediction of the QoE more suitable are non-monotonic functions between the values of QoS and QoE.

2. Scientific contributions

The scientific contributions in the publications from the list of publications presented as a habilitation thesis, can be grouped in the following research areas:

- Development of methods for conceptual modelling of service systems.
- Generalized net models of service systems.
- Analytical modelling of overall telecommunication systems.
- Modelling of the quality of service.

2.1. Methods for conceptual modelling of service systems

Various approaches to the conceptual modelling of overall telecommunication systems with QoS guarantees are studied in [1]. Three conceptual models are presented: conceptual model of overall telecommunication system based on service systems theory; GN model of the Switching stage of an overall telecommunication system; GNCP model of the Switching stage of an overall telecommunication system. The models are compared in view of the concepts used in them and the clearness of the graphical representation. As a result, a conclusion is made that the conceptual models can be invariant to the modelling sub-concepts and tasks.

For the first time, GN representations of the basic elements of service systems theory are proposed in [2]. Although GNs are widely used in the modelling of service systems, until now no systematic approach can be found in the literature to the construction of such models which uses already existing conceptual models from service systems theory. GN representations of the following elements are proposed: Generator, Terminator, Transportation, Delay, Server, Information gathering, Unifying transition, Distributive transition, Queue. The functions of these elements are represented through the predicates of the index matrices of the transitions' condition. The results allow for comparison of various possible representations of the modelled objects in the languages for computer modelling and simulation. Apart from that, the proposed representations allow easy construction of GN models based on given conceptual models from service systems theory, and vice versa. This is the first step towards solving the important methodological problem for determining a system of base model concepts for modelling of service systems, which allows graphical generalizations and in which the different functions of the elements are represented graphically in different ways. The development of a systematic approach to the modelling of service systems continues in [6] where a GN representations of more complex elements of service systems theory are proposed. The considered constructions are: information feedback; information feedback and feedforward; requests feedback. For each of them, a GN model is constructed using the corresponding conceptual model in terms of service systems theory. For the information feedback and feedforward, apart from a model using ordinary GNs, GNCP models are also constructed. The GNCP models allow simpler graphical representation of the net. The proposed representations make the modelling of service systems, and in particular of telecommunication systems, easier.

In [3], a new conceptual model is proposed of an overall telecommunication system with virtual channel switching, including users' behavior, with Bernoulli–Poisson–Pascal (BPP) input flow of requests, repeated requests, finite number of homogenous terminals, losses due to abandoned and interrupted dialing; blocked and interrupted switching; not available intent terminal; blocked and abandoned dialing; abandoned communication and queuing system with FIFO discipline of service of the requests at the switching stage. The proposed model is constructed on the basis of the service systems theory.

2.2. New generalized net models of service systems

GN model of overall telecommunication system, including a queuing system at the switching stage, is described in [7]. The GN model is based on the classical conceptual model of overall telecommunication system with virtual channel switching, including users' behavior, with Bernoulli–Poisson–Pascal (BPP) input flow of requests, repeated requests, finite number of homogenous terminals, losses due to abandoned and interrupted dialing; blocked and interrupted switching; not available intent terminal; blocked and abandoned ringing; abandoned communication. The model is constructed using the proposed in [2,6] GN representations of base elements of service systems theory and the models of queuing systems proposed in [Tomov et al, 2018; Tomov et al, 2019]. The graphical representation of the GN model of overall telecommunication system with queuing is divided into 4 parts, each of which corresponds to one of the stages: Dialing, Switching, Ringing, Communication. A naming system is proposed for the places of the GN which correspond to base virtual devices the parameters of which characterize the overall state of the system.

Three GN models of flexible manufacturing systems are described in [8]. In the first model, three types of machines and three types of workpieces are considered and decision making is included when some conflicts are generated in the system. Each machine is evaluated with an intuitionistic fuzzy pair. The degrees of membership and non-membership of the IFP are obtained by determining the relative part of the good and bad workpieces, respectively. The degree of uncertainty is given by the relative part of the workpieces which are sent to another machine. In the second GN model, again three machines are considered, but additional conditions are included regarding which machine what type of workpieces can service. Evaluations of the machines are again obtained in the form of IFPs. The third GN model considers a more complex manufacturing process which includes transport units which transfer the machine elements to the warehouse, to the machines and to the measuring instruments. GNCP is used in the model with the aim of simplifying the graphical representation.

2.3. Analytical modelling of service systems

In [3], using the proposed conceptual model of overall telecommunication with queuing system, for the purpose of the analytical modelling, the notions of system tuple and base tuple are introduced. Classification of the parameters of the base tuple into static and dynamic is made. Main assumptions about the system are formulated which makes the analytical modelling easier.

The main result is the derivation of analytical expressions for the important dynamic parameters of the queuing system with limited capacity of the buffer and server, and FIFO discipline of service of the requests, in the context of overall telecommunication system. These are expected length of the queue (Yq), expected total number of requests in the buffer and server (Ys+q), the mean time for service of a request in the buffer (Tq), probability for blocking in the buffer (Pbq).

The obtained analytical expressions for the parameters of the queuing system in the context of overall telecommunication system with QoS guarantees and queuing system in the switching stage is a first step towards the construction of a new analytical model of overall telecommunication system.

In [7], using the GN conceptual model of overall telecommunication system with queuing in the switching stage for the purpose of the analytical modelling of overall telecommunication systems, a naming system for the places of the GN which correspond to base virtual devices the parameters of which characterize the overall state of the system is proposed. Assumptions about the system are formulated and base tuple is introduced. The parameters of the base tuple are classified into static and dynamic. Using the graphical representation of the GN and the methods of the Teletraffic theory and the Probability theory, analytical expression for the intensity of the traffic of the called terminals (Yb) is derived. This shows that GNs are suitable for the construction of analytical models of overall telecommunication system.

2.4. Modelling of QoS

The problem for prediction and presentation of the Quality of Experience (QoE) in overall telecommunication systems is discussed in [4]. Four approaches to the conceptual normalization are proposed. An indicators' scale normalization is proposed. Numerical illustration is presented. The values of the QoS indicators are predicted using analytical model of overall telecommunication system in which the parameters, characterizing the users' behavior, as well as parameters regarding the technical characteristics of the net, are considered known. The following normalizations are proposed:

- Structural normalization.
- Functional normalization.
- Causal normalization.
- Conceptual normalization.
- Name normalization.
- Indicators' scale normalization.

Indicators for QoS in telecommunications are defined in the ITU recommendations and they belong to various types. With regard to this, a natural assumption is made in [4] for the numerical meaning of the terms 'high quality' and 'low quality'. Numerical results are presented regarding the proposed method for normalization of conceptual and analytical models of overall telecommunication system and normalization of the indicators' scale for QoS and QoE. The QoS indicator Overall Network Call Efficiency (NCE) and the corresponding QoE values are presented in the same proposed scale, in the entire theoretical interval of the network load. The values of the QoE indicator (MOS of NCE), corresponding to the NCE, are calculated using a modification of the Weber-Fechner Law. Presented results show advantages of the proposed overall model normalizations techniques towards adequate prediction and presentation of QoE in conjunction with QoS, in the overall telecommunication systems.

The problem for traffic quality composition in service compositions is studied in [5]. The causal structure is presented through virtual devices corresponding to parasitic, carried and served traffic. The causal composition and decomposition of traffic quality is presented both graphically and analytically. A naming system for the virtual devices is proposed which takes into account the levels of inclusion of the base virtual devices in the comprise virtual devices. Several aggregations of traffic quality in compositions of services in the cases of parallel and consecutive compositions of virtual devices are derived.

In the proposed approach for quality aggregation, the services are represented through virtual devices and three indicators for QoS are used: flow efficiency (Qf), traffic efficiency (Qy) and time efficiency (Qt).

General graphical representation of causal decomposition and detailed graphical representation of causal decomposition of the traffic inside a virtual device are proposed. In it, two types of service of the requests in the causal device Carried (cx) are considered. They are denoted by *zero* and *real*, respectively. The requests entering the zero device are serviced without delay, while those entering the real device – with delay.

Three indicators for a base virtual device x are defined: traffic indicator (Qyx), flow indicator (Qfx) and time indicator (Qtx). Analytical expressions for the traffic indicator and for the flow indicator are derived. Analytical expressions for the traffic and flow indicators in the case of alternative composition of virtual devices are also derived.

3. Conclusion

The described scientific contributions in the publications presented as a monography are a base for the development of a methodology for conceptual and analytical modelling of service systems and, in particular, of telecommunication systems.

As a continuation of the research over the problems of the conceptual modelling of service systems, it is necessary for GN representations of other often used constructions of the service systems theory to be proposed. Not well-studied remains the problem for representation through GNs of comprise virtual devices, which contain embedded devices on several levels.

Regarding the analytical modelling of overall telecommunication systems, the results presented here are further developed in [Andonov et al, 2019], where an analytical model of overall telecommunication system, including a queuing system at the switching stage, is constructed. The derived system of equations is studied for existence and uniqueness of the solution.

The results about the modelling of the QoS in service systems will be applied to the models of telecommunication systems such as the model in [Andonov et al, 2019].

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