SUMMARY OF THE SCIENTIFIC CONTRIBUTIONS IN THE PUBLICATIONS FOR PARTICIPATION IN THE COMPETITION

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The scientific contributions made in the publications from the complete list of publications can be grouped in the following main directions of scientific research:

- Definitions of new extensions of the ordinary Generalized Nets (GNs) – [8, 11, 16, 17, 24].
- Investigation of the properties of the new extensions of the ordinary GNs– [5, 10, 13, 35, 50].
- Research related to other problems of the GNs theory – [5, 6, 14,15,16].
- GNs models of processes in telecare/telemedicine – [3, 4, 7, 9, 18, 25].
- Other GNs models – [12, 20, 22, 27, 28, 29, 34, 37, 42, 44].
- Conceptual modelling of service systems – [29, 30, 32, 34, 43, 45, 48,49].
- Modelling of telecommunication networks – [23, 28, 31, 33, 38, 39, 40, 41, 45, 46].
- Other contributions – [1, 2, 21,26, 36].

The scientific contributions made in the publications from the list for the present competition can be grouped as follows:

- Contributions to the theory of the GNs.
- GNs models in telemedicine/telecare; GNs models of the human body; GNs models of service systems.
- Modelling of telecommunication systems.
- Other contributions.

1. Contributions to the GNs theory

A new extension of the class of the ordinary GNs – Generalized Nets with Characteristics of the Arcs (GNCA) is defined in [5]. In GNCA, apart from the tokens, as in the case of the ordinary GNs, characteristics are also assigned to the arcs of the net if tokens have been transferred through them at the current time step. It is proved that the class of all GNCA – Σ_{CA} – is a conservative extension of the class of the ordinary GNs - Σ, i.e., the functioning and the results of work of every GNCA can be represented by an ordinary GN. The proof of the theorem for conservativeness of the class Σ_{CA} is constructive. For an arbitrary GNCA, an ordinary GN is constructed which represents the functioning and the results of the work of the given GNCA. Taking into account the fact that the class of the Generalized Nets with Characteristics of the Places (GNCP) Σ_{CP} is a conservative extension of the class Σ and the transitive property of the relation „≡", it is shown that for every GNCP there exists a GNCA which represents its functioning and preserves the results of its work. Also, for every GNCA there exists a GNCP which represents its functioning and preserves the results of its work.

The extension GNCA allows for the definition of classes of reduced GNCA. This, in turn, leads to the definition of a third class of minimal reduced GNs in which characteristics are assigned only to the arcs of the net.

GNCA are especially suitable for the modelling of transport networks in which the ways, railways and the inland water ways, etc., can be represented by arcs of the GNs. In such models, the possibility of assigning characteristics to the arcs can lead to significant simplification of the graphical representation of the nets.

The problem for optimization of GNs models is studied in [22]. Some of the existing operators for complexity of GNs are summarized and new ones are defined. By using the relations of inclusion and equivalence in terms of the results of the work defined over GNs, relations of inclusion and equivalence with regard to arbitrary operator for complexity are defined. A general scheme for optimization of GNs models is described. As a result of the application of certain operators over GNs to a given GN model, a sequence of GNs is obtained in which, for every two consecutive nets, the relation of inclusion in terms of the results of the work with regard to the operators for complexity holds. The optimization procedure stops when the minimal number of concepts, specified in advance, which are required to be present in the GN model, is reached. The procedure is illustrated for a GN model of a queuing system with limited capacities of the buffer and server and FIFO discipline of service of the requests. In this case, the stopping criterion of the procedure is the reaching of a net with minimum acceptable number of transitions and minimum acceptable number of places of the net. The initial GN model is modified in three stages. At every stage, a GN model of a queuing system is obtained. For each of the GNs, the values of the operators for complexity of GNs are evaluated and the relations of inclusion in terms of the results of the work with regard to the operators for complexity which hold are listed. In the final GN model, a GNCP is used.

The operators for complexity over GNs and the relations over GNs with regard to these operators serve as a base for conceptual optimization of GN models. While in most of the existing approaches to the conceptual optimization, in which subjective criteria are used, the proposed approach in [22] allows the construction of optimization algorithms, suitable for computer implementation.

2. Generalized net models

The GN models in the list of publications presented at the competition can be grouped as follows:

- GN models of processes in telemedicine/telecare.
- GN models of systems of the human body.
- GN models of service systems.

2.1. Generalized net models of processes in telemedicine/telecare.

The applicability of the apparatus of the GNs to the modelling of enhancing technologies and, more specifically, to telecare/telehealth processes is discussed in [1]. The purpose of the models is to provide the elderly people and/or people with chronic conditions or people with disabilities with possibility to lead a fulfilled life. A GN model of an enhancing technology system is proposed which emphasizes on the connection between the sensors for monitoring of humans' health and the telecommunication (mobile) network. Three types of sensors are considered: attached to the human body, measuring biomedical parameters such as ECG signal or SPO2; stationary sensors which are placed in the room and which measure for example the concentration of CO; sensors attached to the human body which are activated by the patients upon the occurrence of an event. Every sensor can send a message to a special medical center where an automatic system determines the priorities of the messages according to the degree of emergency. In case that the system fails to determine the priority of the given message, the message is sent to an operator. Autonomous sensors can connect to the network through AT command and this is enough for their work. Non-autonomous sensors work in a waiting regime and observe the patients' reactions. When a reaction occurs, they are connected to the network and send a message to the medical center. The proposed GN model considers analysis of the messages and the data, obtained from the sensors at a specialized medical center by a specialized software or human operator. After checking of the correctness of the signal, in accordance with emergency criteria set in advance, a decision is made whether the signal has to be confirmed or it is necessary that the patient be visited by a medical doctor. The model can be used for simulation of various situations through changes of the number of emergency cases to which a help from the available medical doctors is needed. As a result, the minimal number needed medical doctors in the medical center can be determined.

The paper [2] is a continuation of the work in the direction of modelling of telemedicine/telecare processes via GNs. A GN model of telemedicine for people with diabetes is proposed. The sensors included in the model are: blood pressure monitor, weight scale, pulse oximeter and blood glucose monitor. Smart filtering of false positive alarm messages is included which reduces the number of events for which the health care person has to take a decision. The GN model can be used to develop a decision support tool for telemedicine for people with diabetes. In the decision making process about an event that has occurred, apart from the sensors information, a possibility to perform a health interview with the patients is stipulated. The proposed GN model allows for the application of a new approach to modelling of flows of information, patients and work (medical) procedures in healthcare units and the health system. Through simulations of the model, the problems connected to restructuring, managing, planning and organization of the health care services can be studied. The model is a base for development of a decision supporting tool and can be easily extended to include evaluations of the costs of the telemedicine center. In [6], a modification of the GN model of telemedicine for people with diabetes is proposed. Active/mobile patients are included in the model and their location is an important parameter of the model.

These models are results of the work of an international team of high-profile specialists within European project MATSIQEL (Models for Ageing and Technological Solutions for Improving and Enhancing the Quality of Life).

2.2. Generalized net models of systems of the human body

For the first time, a GN model of the human body secretory system is constructed in [12]. The GN consists of 8 transitions, 16 places and 11 different types of tokens. Among the transitions of the net, 5 transitions represent the functions of the following systems and organs of the human body, together with the corresponding processes in them: cardiovascular system; kidneys; bladder; nervous system; muscles. The main systems and organs are presented in a simplified form. The use of the apparatus of the GNs for modelling of the secretory system allows the proposed model to be modified into a more detailed one if needed. Also, the model can be included in the existing GN model of the human body or it can be used for teaching students, and as a base for a simulation model of various situations with the aim of supporting the decision-making process.

The research on the modelling of the systems and organs of the human body with GNs is continued in [15]. A GN model of the abdominal aorta and its branches as a part of the vascular system is proposed. The model consists of 24 transitions, 50 places and 14 types of tokens. The model of the cardiovascular system aims at enriching and supplementing the knowledge about it, or at least about its parts. Objective criteria can be formulated and parameters can be chosen which, upon simulation of the model, can enhance the understanding of the state of the system, the presence and weight of the pathology, the risk degree and a relatively correct prognosis for the development of one disease or another.

Publications [12] and [15] have been prepared with the help of medical experts specializing in the corresponding area.

2.3. Generalized net models of service systems

GN models of service systems are included in the papers [10,11,16,17,19,22,23]. First, GN representations of the basic elements of service systems theory are proposed in [10]. 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 [16] 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 is 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.

Some of the models of queuing systems proposed in previous publications are extended and modified in [11] with the inclusion of Intuitionistic Fuzzy Pairs (IFPs) and Interval-Valued Intuitionistic Fuzzy Pairs (IVIFPs), which determine the way (discipline) of service of the requests by the queuing system. The buffer has limited capacity and is represented by two GN transitions. The places of the buffer are represented by places of the GN. Simple disciplines of service of the requests are considered (FIFO, LIFO), as well as more general models with IFPs (IVIFPs), in which the requests can change their parameters and places within the buffer.

The requests are represented in the net by tokens in the characteristics of which the required information about the request is stored and, in addition, an IFP or IVIFP. The pairs are interpreted as degrees of validity and non-validity (or correctness and incorrectness) of the request. The various disciplines of service of the requests are implemented through changes of the predicates of the index matrix of the transitions condition. In the first GN model, for instance, a token from an input place of the transition corresponding to the buffer, can be transferred to an output place, i.e., can serviced by the buffer device, if it has the largest μ-value of the IFP compared to the rest of the tokens in the input places of the transition. Alternative disciplines of service are also described, in which the serviced requests are those with the lowest ν-value of the corresponding IFP, as well as with largest $\langle \mu, \nu \rangle$-value.

In the second GN model, the queuing discipline is determined by the belonging of the values of the IFP for a given token α - $\langle \mu_\alpha, \nu_\alpha \rangle$ - to the corresponding intervals of the IVIFP $\langle M_j, N_j \rangle$ of an input place with index j. Again, three forms of the predicates are considered.

In the last GN model of queuing system described in [11], the GN model of a queuing system in which the requests change their places within the buffer is extended with the inclusion of IFPs (IVIFPs). In the new GN model, the requests change their places if the values of the corresponding IFPs satisfy some criterion given in the characteristics of some special token of the net.

The discipline of service of the requests in all of the proposed GN models is implemented through the predicates of the index matrix of the transitions' condition. This allows for the discipline of service of the requests to be changed without changing the structure of the net, i.e., the graphical representation of the GN is preserved.

The modelling of queuing systems through GNs continues in [19], where two GN conceptual models of the causal structure of a queuing system are proposed:

simple and detailed model. In the models, a representation of the comprise virtual devices is proposed which can be used in the models of overall telecommunication networks, consisting of a large number of base virtual devices embedded in comprise devices on several levels. A naming system for the places of the GN is proposed which enhances the analytical modelling of queuing systems, and, more specifically, the quality of service in the queuing systems as a composition of qualities of service in the buffer and server.

Four conceptual GN models of queuing systems with finite capacities of the buffer and server and FIFO discipline of service of the requests are studied in [22] as a part of a procedure for conceptual optimization of GN models. The last – fourth model – uses GNCP and represents the optimal conceptual model of a queuing system for which the values of some selected operators for complexity are the minimum acceptable values.

A GN model of biometric access control system is described in [17] in which 8 parameters are used. The values of the parameters are obtained through the following procedures: voice verification/identification; full face verification/identification; left profile verification/identification; right profile verification/identification; handwriting verification/identification; iris verification/identification; finger verification/identification; signature verification/identification. The model allows the use of different confidence levels when granting access.

Three GN models of flexible manufacturing systems are described in [23]. 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.

3. Modelling of telecommunication systems

A significant part of the scientific contributions in the publications concerns the modelling of telecommunication systems. The results can be divided into three groups:

- Conceptual modelling of telecommunication systems.
- Analytical modelling of telecommunication systems.
- Modelling of the quality of service in telecommunication systems.

3.1. Conceptual modelling of telecommunication systems

Various approaches to the conceptual modelling of overall telecommunication systems with QoS guarantees are studied in [4]. 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.

In [9], 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. For the purpose of the analytical modelling, the notions of system tuple and base tuple are introduced. Classification is made of the parameters of the base tuple into static and dynamic parameters. Main assumptions about the system are stated which allow the easier construction of analytical model. The authors use their experience in the analytical modelling of the classical model of overall telecommunication system.

A method for prediction of the values of parameters, characterizing the Quality of Experience (QoE) in overall telecommunication system, including users and telecommunication network, is proposed in [13]. The method is based on an overall normalization approach of the models, including conceptual normalization. By conceptual normalization, we mean the use of non-coinciding concepts and concepts with unclear meaning. The proposed conceptual normalization includes more precise definitions than those of ITU (International Telecommunication Union) for carried, served and parasitic traffic. The proposed definitions allow better and more accurate characterization of the traffic and the QoS.

GN model of overall telecommunication system, including a queuing system at the switching stage, is described in [14]. 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 dialing; abandoned communication. The model is constructed using the proposed in [10] GN representations of basic elements of service systems theory and the models of queuing systems proposed in [11]. 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.

3.2. Analytical modelling of telecommunication systems

The contributions, concerning the analytical modelling of overall telecommunication systems are presented in [9, 14, 21]. In [9], using the proposed conceptual model of overall telecommunication system with queuing, 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 the 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 [14], 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.

A summary of methods for modelling of overall telecommunication systems developed at the Institute of Mathematics and Informatics of the Bulgarian Academy of Sciences is presented in [21]. A detailed approach to the analytical modelling is described, which uses: a list of assumptions about the system; naming system for the parameters of the virtual devices; qualifiers in the names of the parameters; teletraffic theory, etc. Apart from the known results related to the method for dimensioning/redimensioning of a given telecommunication network, which uses the analytical model of overall telecommunication system, analytical expressions for the parameters of the queuing system in the context of overall telecommunication system are derived. These are the probability for blocking in the buffer, the length of the queue, mean service time of the waiting requests in the buffer, as well as the mean service time for all requests in the buffer – the waiting and the non-waiting.

3.3. Modelling of the QoS in telecommunication systems

The problem for prediction and presentation of the Quality of Experience (QoE) in overall telecommunication systems is discussed in [13]. 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 [13] for the 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. The presented results show the 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 [18]. 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.

The problem for the presentation of the traffic quality in queuing systems, as a composition of the quality of the components of the queuing systems, is studied in [20]. The queuing system is considered a part of information service system. The causal structure of the queuing system is extended with not-served traffic devices and consists of 5 causal virtual devices. The naming system for the virtual devices is also extended. The concepts for time for partial service and "pie" intensity of the traffic are considered. This allows for the easier and clearer graphical and analytical modelling, and definitions of indicators for QoS through aggregation of QoS of the embedded components of the queuing system. The results can be applied to the measurement, prediction and partial management in real information service systems.

4. Other scientific contributions

An auxiliary technique for InterCriteria analysis is proposed in [3]. It is also based on index matrices, however, since the considered estimates (again in the form of intuitionistic fuzzy pairs) are not pair-wise but triple-wise, it is three dimensional. The minimum number of required data needed to be stored, for the proposed technique, is given. Algorithms for evaluation of the degrees of agreement/disagreement between three criteria and two criteria are described.

A GN model of multi-expert multi-criteria decision making procedure is presented in [8]. The model is extended with the inclusion of InterCriteria analysis of the criteria used by the experts. This addition to the standard decision making procedures, with the help of which, at the end of the concrete decision making procedure the criteria used by the experts are modified in such a way that during the next procedure, the experts work with modified set of criteria. Included in the model are: a set of measurement tools which take part in the decision making process; a set of considered alternatives; a set of criteria (ordered) which are used for evaluation of the alternatives. The experts use given criteria or criteria proposed by the experts during the current procedure. Each expert uses only those criteria which he prefers, and has his own rating in the form of intuitionistic fuzzy pair. This rating is updated during the functioning of the net. After performing InterCriteria analysis, an index matrix of agreement between the criteria is obtained. Lists with "good" and "bad" criteria are obtained using meta criteria for distance between the criteria.

For the first time, in [7] are defined the notions of intuitionistic fuzzy mode, mediane and mean element, as well as of a set of intuitionistic fuzzy modes, medianes and mean elements. Algorithms are described for determining of δ-IF mode; set of δ-IF modes; δ-IF mediane; set of δ-IF medianes. Numerical examples are given which illustrate the new notions.

List of publications for participation in the competition

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