AN OVERVIEW OF SOME CONCEPTUAL MODELS OF QUEUING SYSTEMS IN SERVICE NETWORKS

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Abstract: The paper summarizes the authors' research in recent years on the conceptual modelling of queueing systems in service networks. The two approaches used are the Service Systems Theory and the Generalized nets. Some of the proposed conceptual models of queuing systems are included in the analytical models of overall telecommunication system developed by the authors. The models are developed with the aim of deriving analytical models. An important direction of research is the conceptual modelling of the causal structure of a queuing system. The proposed causal conceptual models are used in the study of the Quality of Service (QoS) composition in service networks.

Keywords: *Conceptual modelling, Generalized nets, Queueing systems.*

MSC: *68Q85, 68M10, 90B22*.

ITHEA Keywords: *C.4 Performance of Systems, H.1.2 User/Machine Systems, I.6 Simulation and Modelling, I.6.0 General, H.1.2 User/Machine Systems, K.6 Management of Computing and Information Systems*.

Introduction

The paper summarizes our recent results in the area of conceptual modelling of queuing systems in service networks. The problem for conceptual modelling of queuing systems appeared when we studied the possibilities to extend the conceptual model of overall telecommunication system described in [Poryazov & Saranova, 2012] with the inclusion of a queuing system at the switching stage. Despite the fact that queuing systems are a part of virtually all service networks, their conceptual models are not well studied in the literature. This is true to an even greater degree about the graphical representation of the models. The model of overall telecommunication system in [Poryazov & Saranova, 2012] is, to our knowledge, the most detailed such model in the literature. In order for a queuing system to be included in this model, we need to construct a conceptual model of a queuing system which has detailed graphical representation and, also, is suitable for 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 environ-ment 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 [Andonov et al, 2019a]. 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 et al, 2018] - Generalized Nets with Characteristics of the Places (GNCP) [Andonov & Atanassov, 2013].

The duration of staying of the requests in the queue has an impact on the Quality of Experience (QoE). This is another reason why 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 the papers [Tomov et al, 2018; Andonov et al, 2018], while in [Poryazov et al, 2018a] four conceptual models of queuing systems are compared. Some of these models are extended in [Andonov et al, 2019b].

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 [Poryazov et al,2020a]. 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 of time for partial service and “pie" intensity of the traffic are considered.

Section 2 summarizes the approaches to the conceptual modelling of queuing systems which are used in the models. In Section 3, the conceptual models of queuing systems based on Service Systems Theory are presented. In Section 4, a summary of the generalized net models of queuing systems is made.

Two approaches to the conceptual modelling of queuing systems

The two approaches which we use in the conceptual modelling of queuing systems are the Service Systems Theory and the theory of the Generalized Nets. In this section, we present the basic concepts of both of these approaches and compare them.

01 Service Systems Theory

In the conceptual models of service networks, base virtual devices are used (see [Poryazov & Saranova, 2012]). A general representation of a base virtual device is shown in Fig. 1. Every such device named x has the following parameters:

- Fx – Intensity or incoming rate (frequency) of the flow of requests (i.e., the number of requests per time unit) to device x;

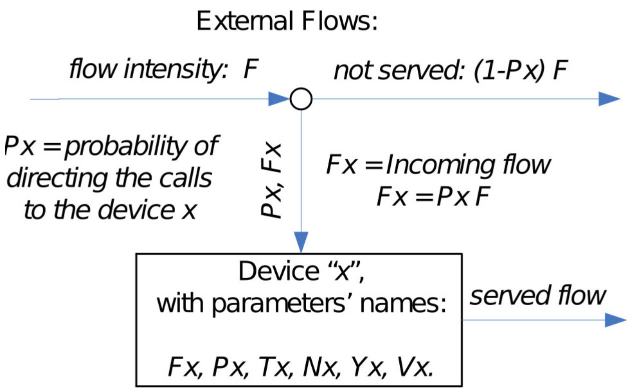

Figure 1: Graphical representation of a base virtual device.

- Px – Probability of directing the requests towards device x;
- Tx – Service time (duration of servicing of a request) in device x;
- Yx – Traffic intensity [Erlang];
- Vx – Traffic volume [Erlang - time unit];
- Nx – Number of lines (service resources, positions, capacity) of device x.

Different types of base virtual devices are used in the models. Some of them together with their graphical representations are shown in Fig. 2.
The devices of each type have specific functions (see [Poryazov & Saranova, 2012]):

- Generator – generates call attempts (requests, transactions);
- Terminator – eliminates each request which enters it;
- Server – models traffic and time characteristics of the model, the delay (service time, holding time) of the requests;
- Transition – selects one of its possible exits for every request which has entered it;
- Queue – buffer device of the queuing system;
- Director – points to the next device to which the request is transferred without delay.

02 On the concept of a generalized net

The GN is a relatively complex object. Detailed definition of a *transition of GN*, *GN* and the algorithms for transition and net functioning can be found in [Atanassov, 2007]. The concepts of a GN model can be divided into:

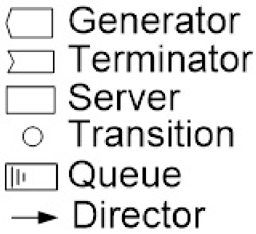

Figure 2: Types of base virtual devices and their graphical representation.

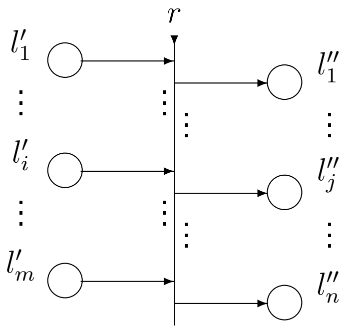

Figure 3: Graphical representation of a transition of a GN.

- model description concepts;
- graphical representation concepts.

First, we shall describe non-formally the elements used in the graphical representation of a GN. GN's *places* are represented by ◯. A GN's *transition* is a part of the net whose graphical representation looks like the object shown in Fig. 3. Every transition contains *transition's conditions* which are graphically represented by .

Like Petri nets, GNs contain tokens which are transferred from place to place through the *arcs* of the net. The arcs are denoted by arrows in Fig. 3. They begin at a place and end at the transition's condition or begin at a transition's condition and end at a place.

The names of the transitions and the places are also included in the graphical representation of the GN model. They can be very important for the understanding of the model by non-specialists in the area of GNs and for the users in general.

To summarize, the concepts of a GN model which are represented graphically are: *transition, place, arc* and the names of the transitions and the places.

Definition 1. Transition of a GN is the following ordered seven-tuple:

$$Z = \langle\langle L', L'', t_1, t_2, r, M, \square \rangle\rangle \,, \tag{1}$$

where

1. L' and L'' are finite non-empty sets of the transition's input and output places, respectively. For the transition in Fig. 3 these sets are:

$$L' = \{l'_1, l'_2, \dots, l'_m\},$$
$$L'' = \{l''_1, l''_2, \dots, l''_n\}.$$

2. t_1 is the current time moment at which the transition can be activated.

3. t_2 is the duration of the active state of the transition.

4. r is the Index Matrix (IM, see [Atanassov, 2007]) of the transition's conditions which determine the output places to which the tokens in the input places can be transferred. It has the form:

$$r = \begin{array}{c|c} & l''_1 \; \dots \; l''_j \; \dots \; l''_n \\ \hline l'_1 & \\ \vdots & r_{i,j} \\ l'_i & (r_{i,j} \; - \; \text{predicate}) \\ \vdots & (1 \le i \le m, 1 \le j \le n) \\ l'_m & \end{array} ;$$

where $r_{i,j}$ is the predicate which expresses the condition for transfer from the i-th input place to the j-th output place.

When $r_{i,j}$ has truth-value "$true$", then a token from the i-th input place can be transferred to the j-th output place. Otherwise, this is impossible.

5. M is an IM of the arcs' capacities. It has the form:

$$M = \begin{array}{c|c} & l''_1 \; \dots \; l''_j \; \dots \; l''_n \\ \hline l'_1 & \\ \vdots & m_{i,j} \\ l'_i & (m_{i,j} \ge 0 - \; \text{natural number or } \infty) \\ \vdots & (1 \le i \le m, 1 \le j \le n) \\ l'_m & \end{array} ;$$

6. $\square$ is the transition type. It is an object having a form similar to a Boolean expression. It has as variables the same symbols that serve as labels for the transition's input places. It is constructed of these variables and the Boolean connectives $\wedge$ and $\vee$. When the value of its type (calculated as a Boolean expression) is "$true$", the transition can become active. Otherwise, it cannot.

Definition 2. *Generalized net E* is the ordered four-tuple

$$E = \langle\langle A, \pi_A, \pi_L, c, f, \theta_1, \theta_2\rangle, \langle K, \pi_K, \theta_K\rangle, \langle T, t^0, t^*\rangle, \langle X, \Phi, b\rangle\rangle , \tag{2}$$

where

1. A is the set of GN-transitions.
2. π_A is a function which gives the priorities of the transitions, i.e., $\pi_A : A \to \mathcal{N}$.
3. π_L is a function which gives the priorities of the places, i.e., $\pi_L : L \to \mathcal{N}$, where

$$L = pr_1 A \cup pr_2 A$$

   is the set of all GN-places.
4. c is a function which gives the capacities of the places, i.e., $c : L \to \mathcal{N}$.
5. f is a function which calculates the truth values of the predicates of the transition's conditions. It obtains the values "$false$" or "$true$", or values from the set $\{0, 1\}$. if $\mathcal{P}$ is the set of the predicates used in a given GN-model, then f can be defined as $f : \mathcal{P} \to \{0, 1\}$.
6. θ_1 is a function which gives the next time-moment when a given transition Z can be activated, i.e., $\theta_1(t) = t'$, where $pr_3 Z = t, t' \in [T, T + t^*]$ and $t \leq t'$. The value of this function is calculated at the moment when the transition terminates its functioning.
7. θ_2 is a function which gives the duration of the active state of a given transition Z, i.e., $\theta_2(t) = t'$, where $pr_4 Z = t \in [T, T + t^*]$ and $t' \geq 0$. The value of this function is calculated at the moment when the transition starts functioning.
8. K is the set of the GN's tokens. In some cases, it is convenient to consider this set in the form

$$K = \bigcup_{l \in Q^I} K_l,$$

   where K_l is the set of tokens which enter the net from place l, and Q^I is the set of all input places of the net.
9. π_K is a function which gives the priorities of the tokens, i.e., $\pi_K : K \to \mathcal{N}$.
10. θ_K is a function which gives the time moment when a given token can enter the net, i.e., $\theta_K(\alpha) = t$, where $\alpha \in K$ and $t \in [T, T + t^*]$.
11. T is the time-moment when the GN starts functioning; this moment is determined with respect to a fixed (global) time-scale.
12. t^0 is an elementary time-step, related to the fixed (global) time-scale.
13. t^* is the duration of the GN's functioning;
14. X is a function which assigns initial characteristics to each token when it enters an input place of the net.
15. Φ is a characteristic function which assigns new characteristics to each token when it makes a transfer from an input to an output place of a given transition;

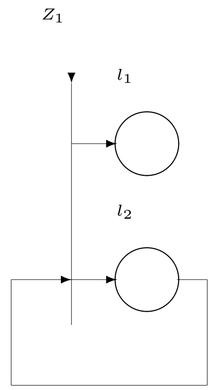

Figure 4: Generalized net representation of Generator.

16. b is a function which gives the maximum number of characteristics a given token can receive, i.e., $b : K \to N$.

The input and output places of the transitions, the IMs of the capacities of the arcs and the types of the transitions determine the static structure of a GN. The dynamic nature of a GN is expressed in the tokens and the transitions' condition. The temporal properties of a GN are presented through the time components T, t^0, t^* and the elements of the set $pr_{3,4}A$, i.e., the functions θ_1 and θ_2 of the transitions. The functions Φ, X and b serve as a GN's memory. The functions π_A, π_L, c are related to the GN's static structure, f and π_K are related to the GN's dynamic elements and θ_1, θ_2 and θ_K are related to the time components of a GN.

03 GN representations of the basic elements of Service Systems Theory

Despite the fact that GNs have been used as a tool for modelling of service systems, and telecommunication systems in particular, starting with the paper [Poryazov & Atanassov, 1997], the connection between the GN conceptual models and the models based on Service Systems Theory had not been studied. In [Andonov et al, 2019a], for the first time GN representations of the basic elements of Service Systems Theory were proposed. The work in this direction continues with the paper [Andonov et al, 2020a] where GN representations of more complex elements of Service Systems Theory are proposed, such as information feedback, information feedback and feedforward and requests feedback. The proposed representations allow for the easier construction of GNs conceptual models of service systems using the already existing models based on Service Systems Theory.

The graphical representations of the proposed GN representations of the basic elements of Service Systems Theory are shown below. The description of the transitions of the GNs can be found in [Andonov et al, 2019a].

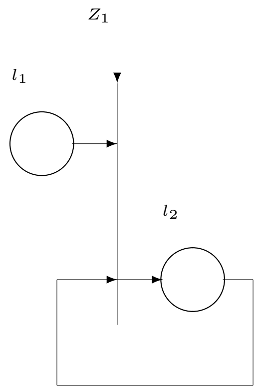

Figure 5: Generalized net analogue of Terminator.

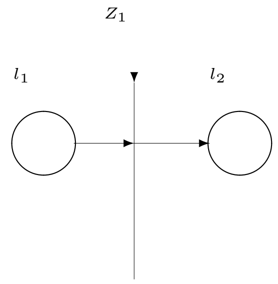

Figure 6: Generalized net representation of Transportation.

031 Generator

The function of the Generator is to create requests, for instance call attempts. Its execution does not increase the model time. The device has characteristics: capacity and time interval between two consecutive requests – usually a pseudo random variable. The requests generated belong to a certain type. A graphical representation of Generator is shown in Fig. 4.

032 Terminator

The Terminator removes the requests from the model. It has capacity. The duration of its execution is 0, i.e. it does not change the model time.

A GN representation of the Terminator is shown in Fig. 5. The requests that should be terminated are represented by tokens in place l_1.

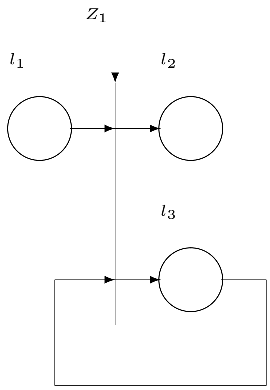

Figure 7: Generalized net representation of Delay.

033 Transportation

The function of the Transportation is to represent the movement of objects from one part of the model to another. It reflects the dynamics of the modeled process. A GN representation of Transportation is shown in Fig. 6. The places of the transition represent two different parts of the modeled system for which there is a flow of information in one direction – from the input place l_1 to the output place l_2.

034 Delay

The Delay is used to represent situation in the modelled process when requests must wait for a certain period of time until the condition for their transfer is satisfied. The GN representation of the Delay is shown in Fig. 7. The tokens in place l_1 representing requests that must wait enter place l_3. They stay there until the condition for transfer is satisfied. The evaluation of the truth value of the predicate corresponding to the transfer of the tokens from input to output places does not change the model time, i.e. it is performed outside of it.

The GN representation can be used not only when requests must wait a given number of steps but also when their further transfer depends on some logical condition and the delay must be determined at any time step. For example, the delay could be as a result of accumulation of many events within the model.

035 Server

The Server represents control or comparison of results with their standard or expected values. This includes checking of requests' quality or quantity parameters, control of the results of experiments, reading documents before taking a decision etc. A GN representation of Server is shown in Fig. 8. The change of the of the characteristics of the requests is modelled through the characteristic function of the places of the GN.

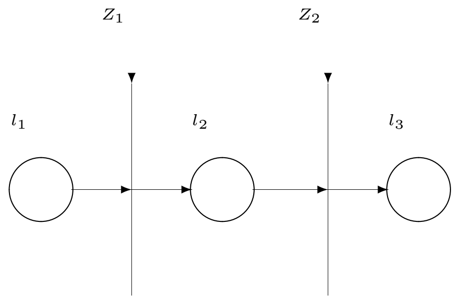

Figure 8: Generalized net representation of Server.

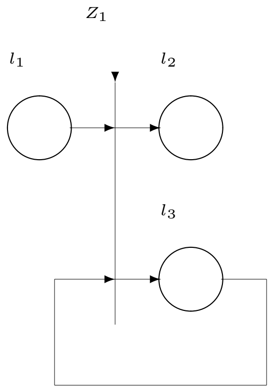

Figure 9: Generalized net representation of Information gathering.

036 Information gathering

The Information gathering denotes the accumulation and storage of data obtained within the model. In particular it describes the passive storage of data. The GN representation of the Information gathering is shown in Fig. 9. The information that must be stored is preserved in the form of characteristics of a token which stays permanently in place l_3.

037 Unifying Transition

The Unifying Transition denotes two channels that merge to form a single channel. Its GN representation is shown in Fig. 10. The tokens entering place l_3 merge to form a single token which preserves their characteristics.

038 Distributive Transition

The Distributive Transition represents one channel that splits into two. Its GN representation is shown in Fig. 11.

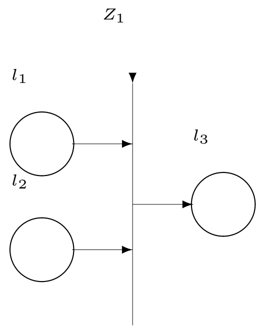

Figure 10: Generalized net representation of Unifying Transition.

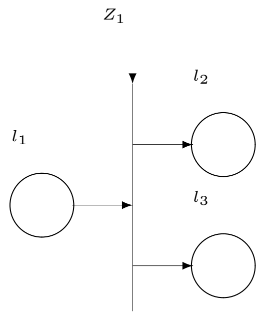

Figure 11: Generalized net representation of Distributive Transition.

039 Queue

The Queue represents waiting lines. It is important to know where the information comes from and what is the management of the queue, i.e. FIFO, LIFO or some other rule. A GN representation of a Queue is shown in Fig. 12. The management of the Queue can be described in terms of GNs in different ways. For example, through the priorities of the places and the predicates of the transition's condition.

Conceptual models of queuing systems based on Service Systems Theory

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For the queuing systems containing buffer and server, the first quantitative models are created by Erlang [Erlang, 1917]. After that newer methods have been used [Kleinrock, 1975]. These systems are used in practically all service networks, including telecommunication, computing, logistic, etc [Otsetova, 2016]. Despite this, in the broad scientific literature their conceptual models are being represented graphically in a very simple way [Gupta & Aurora, 2018]. The existing conceptual models are not suitable for inclusion in a conceptual model of overall telecommunication network such as the one described in [Poryazov & Saranova, 2012]. Therefore, different conceptual models of queuing systems based on Service Systems Theory have been proposed and compared in the papers [Poryazov et al, 2018a; Andonov et al, 2019b; Poryazov et al, 2020b]. Later, in the paper [Poryazov et al,2020a] a conceptual

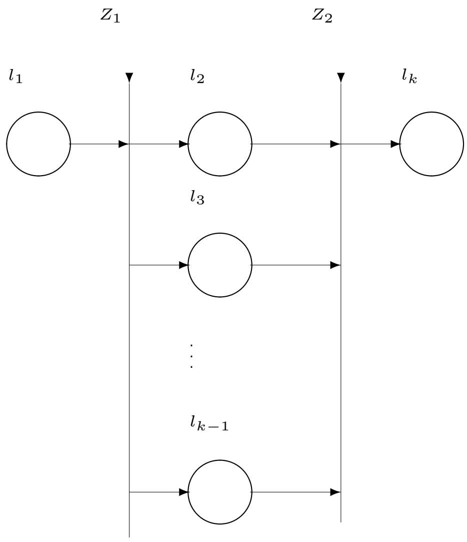

Figure 12: Generalized net representation of a Queue.

model of the causal decomposition of the traffic in a queuing system is proposed. Here, we summarize briefly these models.

04 Classical conceptual model of a queuing system

The classical representation of a queuing system is shown in Fig. 13. The buffer device is denoted by **ws** (abbreviation of “waiting for server”). The server is denoted by **s**. A generator generates requests with flow intensity $ofr.Fws$ (intensity of the offered flow of requests to the **ws** device). If both the server and the buffer have reached their capacities, the requests enter the **bws** device (abbreviation for “blocked waiting for switch") with probability $Pbws$. The “blocked queuing” device is outside the queuing system. It corresponds to the duration of specific signalization, e.g. listening of the busy tone in telephone systems. From there the requests leave the system through the terminator device after the **bws** device. If the buffer hasn’t reached its capacity, then the requests enter the **ws** device with probability $1 - Pbws$. The requests wait in the buffer to be serviced if the server has reached its capacity. Otherwise, they are sent without delay to the server. In both cases, the flow intensity of the requests entering the server is denoted by $inc.Fs$.

05 Detailed conceptual model of a queuing system

An extension of the classical conceptual model of a queuing system is shown in Figure. 14. As above, a generator generates offered requests to the server with flow intensity $ofr.Fws$. If the queuing system has reached its capacity, i.e., both the server (**s**) and the buffer (**ws**) have reached their capacities, the requests are sent to the **bws** device with probability $Pbws$ and from there they leave the system through the terminator. Otherwise, with probability $1 - Pbws$ the requests enter the **ws** device. Here,

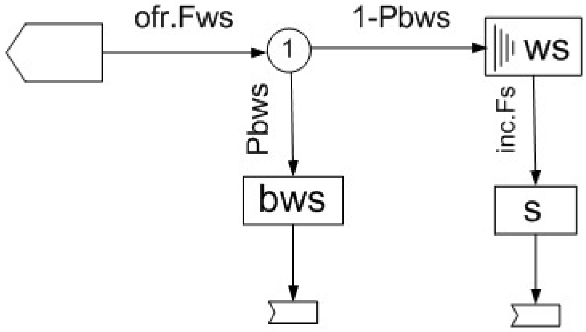

Figure 13: Classical conceptual model of a queuing system.

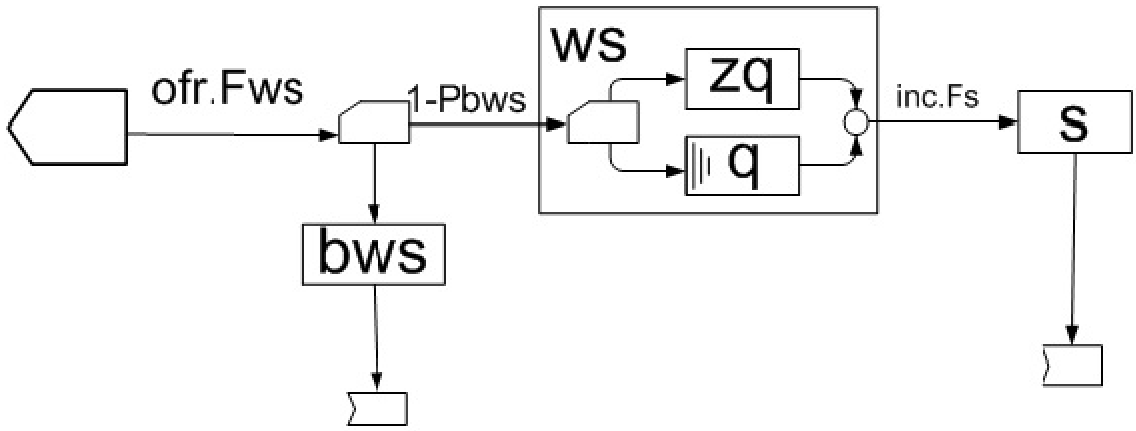

Figure 14: Extension of the classical conceptual model of a queuing system.

the **ws** device is a comprise virtual device, i.e. it contains other devices. The enter switch device inside the **ws** device sends the requests to the zero queuing (**zq**) device when the server has not reached its capacity. From there without delay, they enter the server. This corresponds to the service of the requests by the server without delay. If the server has reached its capacity, the requests are sent to the **q** device. This corresponds to the service of the requests with waiting.

This extension of the classical model allows for the two ways of service of the request in the queuing system to be represented graphically: service with waiting and service without waiting. The mean service time of the requests in the buffer (Tws), for both the waiting and the non-waiting requests, is given by

$$Tws = Pq\ Tq + (1 - Pq)\,Tzq\,, \tag{3}$$

where Pq is the probability that the request is serviced with waiting and Tq is the mean service time in the buffer for the waiting requests. Tzq is the duration of service in the buffer without waiting.

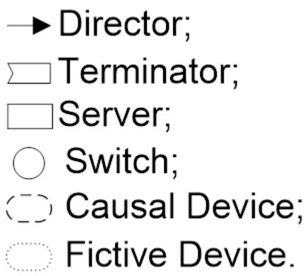

Figure 15: Base virtual device types and their graphical representations.

06 Causal structure of a qeueuing system

The importance of the Quality of Service (QoS) indicators grows with the usage of the informational service networks and it became a commodity in 2015 [Varela et al, 2015]. The QoS and Quality of Experience (QoE) are defined in different ways, but we follow the definition in standardization documents such as the ITU-T [ITU-T, 2017]. The prediction of the overall network quality, as a function of qualities of composed services, is a foremost question in service networks design and maintenance. There are two main approaches to QoS aggregation - analytical (e.g. [Zheng et al, 2011]) and simulational (e.g. [Gatnau et al, 2013]).

In order to study the problem for the QoS composition in queuing systems, first in the paper [Poryazov et al,2020a] conceptual models of the causal structure of virtual devices with limited and unlimited capacities are proposed. A special notation of the parameters is proposed and three types of quality indicators are defined: Traffic Quality Indicators, Flow Quality Indicators and Time Quality Indicators. The proposed approach is applied to a queuing system with limited capacity of the buffer and server.

07 Causal structure of a device with limited capacity

The base virtual devices used in the causal decomposition of the traffic together with their graphical representations are shown in Fig. 15.

The devices of each type have specific functions (see [Poryazov & Saranova, 2012]):

- Director – this device points unconditionally to the next device, which the request shall enter but without transferring, changing or delaying it.
- Terminator – this device eliminates every request entered (so it leaves the model without any traces).
- Server – this device models the delay (service time, holding time) of requests in the corresponding device without their generation or elimination. It models also traffic and time characteristics of the requests processing.
- Switch (Transition) – this device selects one of its possible exits for each request entered, thus determining the next device where this request shall go to.

- Causal device – virtual device defined for presentation of causes of service ending, e.g., successful (carried) or not (interrupted, abandoned, etc.).
- Fictive device – device presenting fictive traffic which is necessary for engineering. For example, not carried traffic is fictive, but it is used for calculating of the offered traffic, which is necessary for device dimensioning.

We group causes of service ending, and corresponding causal devices, in generalized comprising causal devices. If device has unlimited capacity, three causal generalizations are enough: “parasitic”, “carried” and “served” (see [Poryazov et al, 2018b]).

The *Parasitic Traffic* in a pool of resources is the traffic, which was unsuccessfully served in the pool. Parasitic traffic occupies real resources but not for a useful service execution.

The *Carried Traffic* in a pool of resources is the traffic, which was successfully served in the pool (and carried to the next service device). We distinguish two types of carried traffic:

- ’zero service’ e.g. zero waiting in a buffer if the buffer is empty and there is free requested place for the service in the following device. The requests are receiving zero service in the causal ’zero service device’ and may be served without delay;
- ’genuine service’ - successfully and real served requests in the pool. The service time is noticeable.

The *Served Traffic* in a pool of resources is any traffic, occupying (using) resources in the pool. The Served Traffic is a sum of carried and parasitic traffic.

Every Causal Device Parameter’s Name is a concatenation:

Causal name =<qualifier><qualifier>.<Parameter’s Symbol>.<Device Name>.

The qualifiers used in the conceptual models of the causal decomposition are:

- crr. = carried;
- gen. = genuine;
- nsr. = not served;
- ofr. = offered;
- prs. = parasitic;
- srv. = served;
- zer. = zero.

’Parameter’s symbol’ is one of letters P, F, T, Y, V, N, as they are described in Section 2. Qualifiers are used to characterize the parameters of the devices [Poryazov et al, 2018b]. Used qualifiers may be two, one or none. If parameter’s symbol is omitted, the causal name is a name of a device (Fig. 16). Device name may be in small or subscript letters. For instance, $crr.Fx$ is the intensity of the carried

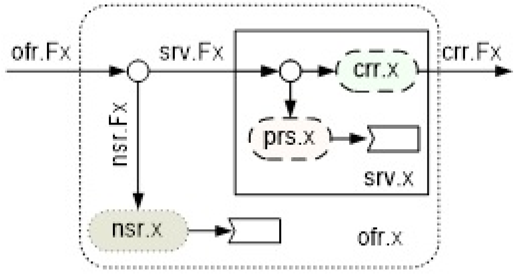

Figure 16: A causal structure of a network portion represented by device x with a limited capacity.

flow of requests of the device x, $prs.Fx$ is the intensity of the parasitic flow of requests of the device x (see Fig. 16).

In the figures, only the names of causal devices may be presented. The names of device parameters are implicit. In Fig. 16 there are three generalized conceptual devices: x, $prs.x$, and $crr.x$.

A more general and real presentation of a service network portion "x" is shown in Fig. 16. It contains a virtual device srv.x with limited capacity. This may cause requests rejection due to lack of service place (call attempts blocking).

The fictive virtual device $nsr.x$ corresponds to the not served traffic, due to blocking or other reasons that would be served, with the same time duration:

$$nsr.Tx = srv.Tx \; . \tag{4}$$

The not served traffic intensity, following the theorem of Little, is given by:

$$nsr.Yx = nsr.Fx \; srv.Tx \; . \tag{5}$$

Therefore, the equivalent traffic offered [ITU-T E.501,] to device x is:

$$ofr.Yx = nsr.Yx + srv.Yx \; . \tag{6}$$

The probability of not service (blocking) $nsr.Px$ may be predicted using a blocking formula, e.g., the B-formula of Erlang. The offered traffic concept leads to necessity of definition of a conceptual device called $ofr.x$ with its parameters P, F, T, Y, and V (the capacity of the offered traffic device is not considered usually). Hence, in Fig. 16 the network portion x is presented by 5 generalized conceptual devices: $prs.x$, $crr.x$, $srv.x$, $nsr.x$ and $ofr.x$ and 2 terminators, 2 transitions and 8 directors.

071 Conceptual model of the causal structure of a queuing system

We propose the following causal conceptual model of a network portion, consisting of queuing system named 'qs' (Fig. 17).

The buffer and the server have limited capacities. The requests to the queuing system with flow intensity $ofr.Fqs$ try to enter the server (s). If there is a free place in the server, the requests pass through the buffer without waiting. If in the server there is no free place for service, the requests may

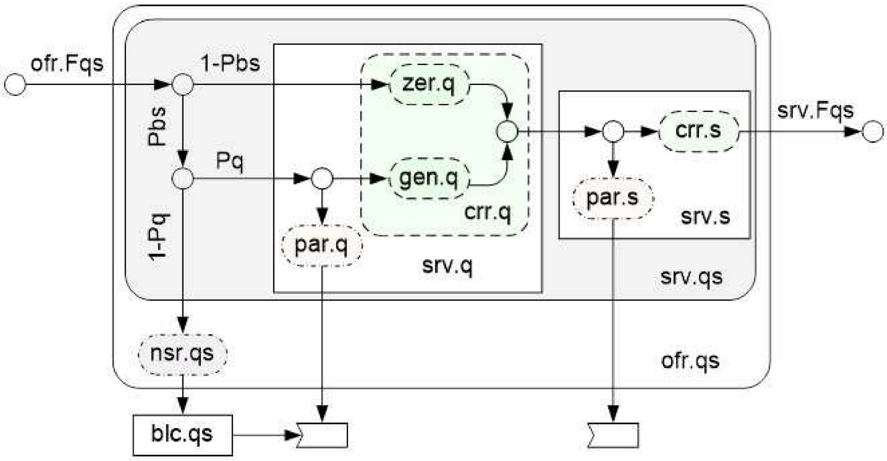

Figure 17: A causal structure of a network portion with queuing system qs with a limited capacity of the buffer and the server.

wait for service in the buffer device. So, the buffer service may be with or without queuing. In Fig. 17 the buffer is denoted by 'queuing device' (q). We consider the probability 'blocked server' (Pbs), i.e. the server to be full and the requests' service to be blocked. The blocked server probability is different from the 'not served in the server' probability because some of the blocked requests, due to the busy server, may be served after waiting in the buffer (the name '$nsr.Ps$' is not shown in Fig. 17).

If the server is not full (the probability of blocked server is less than one), with a probability of $1 - Pbs$ the requests pass through the buffer without queuing, in the zero queuing ($zer.q$) device.

With a probability of Pbs (blocked server) the server is busy and the requests try to enter the queue in the buffer, with a probability of Pq. If they enter the queue, the waiting may be successful in the genuine queuing ($gen.g$) device, or unsuccessful in the parasitic queuing ($prs.q$) causal device.

The following assumptions have been stated.

Assumption 1: All considered processes are in a stationary state. The values of all parameters are random and we consider their means (or mathematical expectations).

Assumption 2: In case of zero queuing, there is no parasitic service in the buffer, due to the little service duration. The causal device 'carried queuing' ($crr.q$) comprises devices 'zero queuing' ($zer.q$) and 'genuine queuing' ($gen.g$). With a probability of $1 - Pq$ the buffer is busy and the requests are not served in the queuing system – they enter the fictive device 'not served in the queuing system' ($nsr.qs$).

After carried queuing, the requests enter the server device ($srv.s$) with a flow intensity of $srv.Fs$ (the name is not shown in Fig. 17) and they are served: successfully in the carried service ($crr.s$) device or unsuccessfully in the parasitic service ($prs.s$) device. Obviously:

$$srv.Fs = crr.Fq\,. \tag{7}$$

The flow intensity of the not served in the queuing system requests ($nsr.Fqs$) is equal to that of the queuing device ($nsr.q$):

$$nsr.Fqs = nsr.Fq,\,. \tag{8}$$

Assumption 3: Following the definition of equivalent traffic offered, the fictive service times in the 'not serve' devices are:

$$nsr.Tqs = srv.Tqs\,. \tag{9}$$

$$nsr.Tq = srv.Tq\,. \tag{10}$$

$$nsr.Ts = srv.Ts\,. \tag{11}$$

Conceptual modelling of queuing systems with generalized nets

The first GN model of a queuing system is described in [Andonov et al, 2018] as a part of a GN model of the Switching stage of an overall telecommunication network. A GN model corresponding to the classical model of a queuing system with FIFO discipline of service of the requests is described in [Poryazov et al, 2018a]. In [Tomov et al, 2018], GN models of queuing systems with various disciplines of service of the requests are described. Some of the models of queuing systems proposed in the previous publications are extended and modified in [Tomov et al, 2019] with the inclusion of Intuitionistic Fuzzy Pairs (IFPs, see [Atanassov, 2013]) 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.

A GN model of the causal structure of a queuing system is constructed in [Andonov et al, 2020]. Also there, the problem for representation of comprise virtual device through GNs is discussed.

In this section, we shall briefly decribe some of these models.

08 Generalized net models of queuing systems

081 First generalized net model of a queuing system

A GN model corresponding to the classical conceptual model of a queuing system is shown in Fig. 18. In comparison to the similar model proposed in [Poryazov et al, 2018a], here only 4 transitions and 10 places are used. This is achieved through the representation of the terminator devices as a places of the GN. This possibility is mentioned in [Andonov et al, 2019a].

Each of the four transitions represents some function of the corresponding base virtual devices.

- Z_1 represents the function of the Generator from Figure 13.
- Z_2 represents the function of Transition 1 from Figure 13.
- Z_3 represents the function of the **ws** device from Figure 13.
- Z_4 represents the function of the **s** (the Server device) from Figure 13.

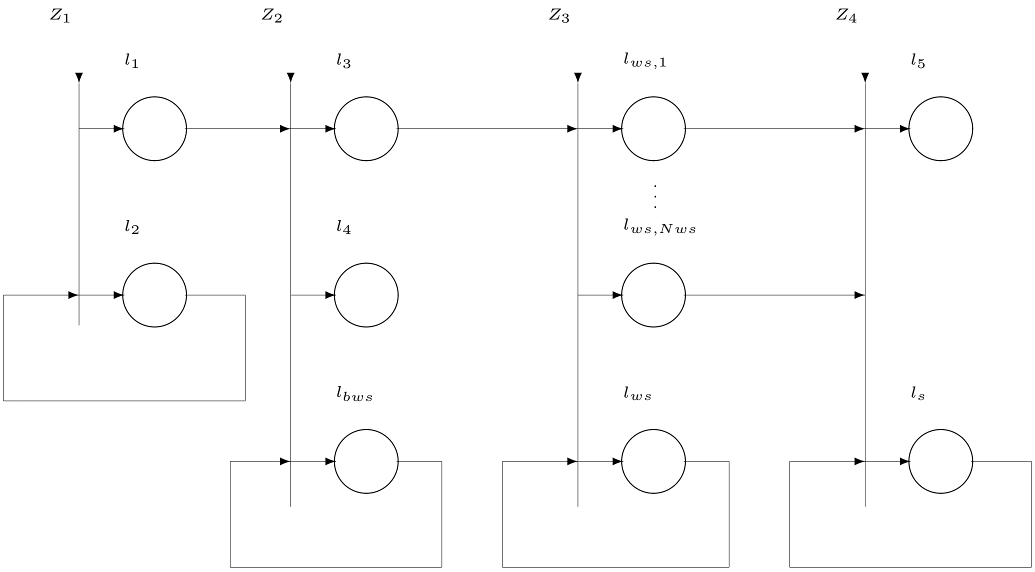

Figure 18: First generalized net model of a queuing system.

The places of the GN represent virtual devices in the following way:

- l_1 and l_2 represent the Generator before Transition 1 in Figure 13.
- l_3 has no analogue in Figure 13.
- l_4 represents the terminator after the **bws** device.
- l_{bws} represents the **bws** device.
- $l_{ws,1}, ..., l_{ws,Nws}$ represent the waiting places of the buffer device **ws**.
- l_{ws} represents the buffer device **ws**.
- l_5 represents the terminator after the **s** device.
- l_s represents the server.

Four types of tokens are used:

- Tokens of type α represent the requests. In the initial time moment of the GN functioning, token α stays in place l_2 with initial characteristic "*formula for generating the flow of requests*".
- Token of type β stays in place l_{bws} in the initial time moment with initial characteristic "initial values of $Y_{bws}, P_{bws}, F_{bws}, T_{bws}, N_{bws}$". It is used to accumulate data about the **bws** device.
- Token of type γ stays in place l_{ws} in the initial time moment with initial characteristic "initial values of $Y_{ws}, P_{ws}, F_{ws}, T_{ws}, N_{ws}$". It is used to accumulate data about the **ws** device. The discipline of service of the requests can be specified in this initial characteristic. In the present paper, we consider only FIFO discipline of service of the requests.

- Token of type δ stays in place l_s in the initial time moment with initial characteristic “initial values of Y_s, P_s, F_s, T_s, N_s”. It is used to accumulate data about the **s** device.

The formal description of the transitions of the GN can be found in [Andonov et al, 2019b].

082 Second generalized net model of a queuing system

The second GN model of a queuing system, which we consider worth mentioning, corresponds to the extended classical model (see Fig. 14). The graphical representation of the GN is shown in Fig. 19. The GN consists of 7 transitions and $14 + Nq$ places where Nq is the capacity of the buffer device. The transitions represent functions of the corresponding virtual devices as follows:

- Z_1 represents the function of the Generator from Figure 14.
- Z_2 represents the function of the Enter switch device before the **ws** device from Figure 14.
- Z_3 represents the function of the Enter switch device inside the comprise virtual device **ws** from Figure 14.
- Z_4 represents the function of the **zq** device inside the comprise virtual device **ws** from Figure 14.
- Z_5 represents the function of the **q** device inside the comprise virtual device **ws** from Figure 14.
- Z_6 represents the function of the Transition device inside the comprise virtual device **ws** from Figure 14.
- Z_7 represents the function of the **s** from Figure 14.

The places of the GN correspond to virtual device in the following way:

- l_1 and l_2 represent the Generator before Enter switch device in Figure 14.
- l_3 has no analogue in Figure 14.
- l_4 represents the terminator after the **bws** device.
- l_{bws} represents the **bws** device.
- l_5 and l_6 have no analogue in Figure 14.
- l_7 and l_{zq} represent the **zq** device in Figure 14.
- $l_{q,1}, ..., l_{q,Nq}, l_q$ represent the waiting places of the buffer device **q**.
- l_8 and l_{ws} represent formally the comprise buffer device **ws** but transitions Z_4 and Z_5 are also part of the comprise virtual device **ws**.

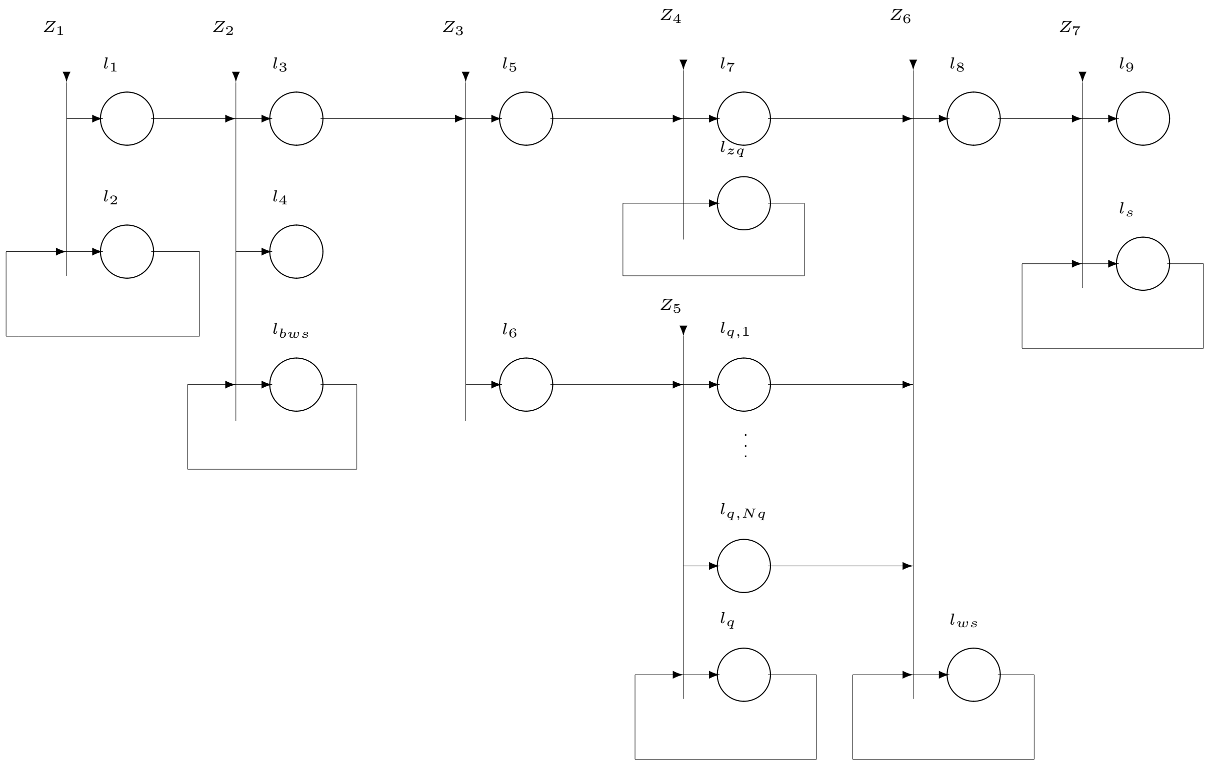

Figure 19: Second generalized net model of a queuing system.

- l_9 represents the terminator after the **s** device.
- l_s represents the server.

Six types of tokens are used in the model:

- Tokens of type α represent the requests. In the initial time moment of the GN functioning, token α stays in place l_2 with initial characteristic “formula for generating the flow of requests”.
- Token of type β stays in place l_{bws} in the initial time moment with initial characteristic “initial values of $Y_{bws}, P_{bws}, F_{bws}, T_{bws}, N_{bws}$ ”. It is used to accumulate data about the **bws** device.
- Token of type γ stays in place l_{zq} in the initial time moment with initial characteristic “initial values of $Y_{zq}, P_{zq}, F_{zq}, T_{zq}, N_{zq}$”. It is used to accumulate data about the **zq** device.
- Token of type δ stays in place l_q in the initial time moment with initial characteristic “initial values of Y_q, P_q, F_q, T_q, N_q”. It is used to accumulate data about the **q** device. The discipline of service of the requests can be specified in this initial characteristic. We consider only FIFO discipline of service of the requests.
- Token of type ϵ stays in place l_{ws} in the initial time moment with initial characteristic “initial values of $Y_{ws}, P_{ws}, F_{ws}, T_{ws}, N_{ws}$”. It is used to accumulate data about the **ws** device.

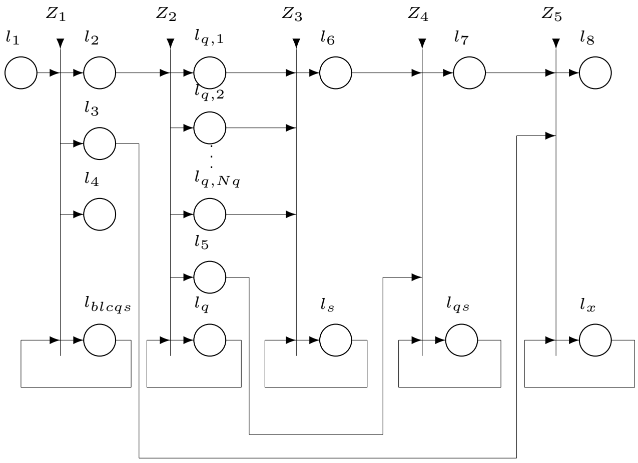

Figure 20: GN model of the simple causal structure representation of a queuing system.

- Token of type ζ stays in place l_s in the initial time moment with initial characteristic “initial values of Y_s, P_s, F_s, T_s, N_s”. It is used to accumulate data about the **s** device.

The formal description of the transitions can be found in [Andonov et al, 2019b].

09 Generalized net model of the causal structure of a queuing system

The first two GN representations of the causal structure of a queuing system are described in [Andonov et al, 2020a].

091 First generalized net model of the causal structure of a queuing system

We propose a GN representation of the simple causal structure of a queuing system in which the comprise devices are included in the gaphical representation. The GN model is shown in Fig. 20.

The GN model consists of 5 transitions and $13 + Nq$ places where Nq is the capacity of the buffer. The labels of those places which represent virtual devices are in the form l_y where “y” is the name of the corresponding virtual device. The transitions represent functions of the corresponding virtual devices as follows:

- Z_1 represents the function of the Switch before the **qs** device.
- Z_2 represents the function of the Director pointing to the **q** device.
- Z_3 represents the function of the Director between the **q** device and the **s** device.
- Z_4 represents the function of the comprise virtual device **qs**.

- Z_5 represents the function of the comprise virtual device **x**.

The places of the GN correspond to virtual devices in the following way:

- l_{blcqs} represents the **blc.qs** device.
- $l_{q,1}, ..., l_{q,Nq}, l_q$ represent the waiting places of the buffer device **q**.
- l_s represents the server device **s**.
- l_{qs} represents the comprise virtual device **qs**.
- l_x represents the comprise virtual device **x**.

Six types of tokens are used in the model:

- Tokens of type α represent the requests. In the initial time moment of the GN functioning, token α stays in place l_1 with initial characteristic “formula for generating the offered flow of requests to the queuing system”.
- Token of type β stays in place l_{blcqs} in the initial time moment with initial characteristic “initial values of $Y_{blc.qs}, P_{blc.qs}, F_{blc.qs}, T_{blc.qs}, N_{blc.qs}$”. It is used to accumulate data about the **blc.qs** device.
- Token of type γ stays in place l_q in the initial time moment with initial characteristic “initial values of Y_q, P_q, F_q, T_q, N_q”. It is used to accumulate data about the **q** device. The discipline of service of the requests can be specified in this initial characteristic. Here, we consider only FIFO (First-In, First-Out) discipline of service of the requests.
- Token of type δ stays in place l_s in the initial time moment with initial characteristic “initial values of Y_s, P_s, F_s, T_s, N_s”. It is used to accumulate data about the **s** device.
- Token of type ϵ stays in place l_{qs} in the initial time moment with initial characteristic “initial values of $Y_{qs}, P_{qs}, F_{qs}, T_{qs}, N_{qs}$”. It is used to accumulate data about the **s** device.
- Token of type ζ stays in place l_x in the initial time moment with initial characteristic “initial values of Y_x, P_x, F_x, T_x, N_x”. It is used to accumulate data about the **x** device.

092 Second generalized net model of the causal structure of a queuing system

A GN model corresponding to the detailed conceptual model of the causal structure of a queuing system (see Fig. 17) is shown in Fig. 21.

The GN consists of 9 transitions and $23 + Nq$ places, where Nq is the capacity of the buffer. The labels of those places which represent virtual devices are in the form l_y where “y” is the name of the corresponding virtual device but the “.” symbol, if present in the name of the device, has been omitted. The transitions represent functions of the corresponding virtual devices as follows:

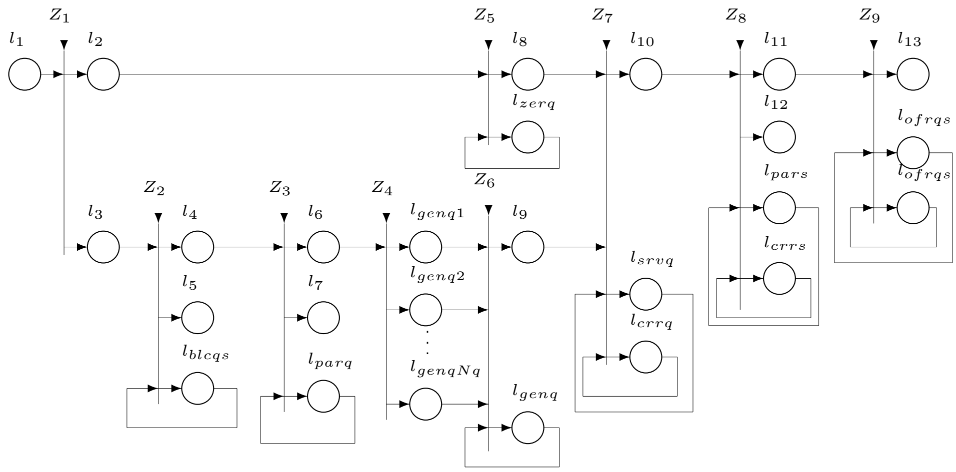

Figure 21: GN model of a detailed representation of the causal structure of a queuing system.

- Z_1 represents the function of the Director outgoing of the first Switch device in Fig. 17.
- Z_2 represents the function of the Director pointing to the **blc.qs** device from Fig. 17.
- Z_3 represents the function of the Switch before the **crr.q** causal device inside the **srv.q** causal device in Fig. 17.
- Z_4 represents the function of the Director entering the causal device **gen.q** in Fig. 17.
- Z_5 represents the function of the causal device **zer.q** from Fig. 17.
- Z_6 represents the function of the causal device **gen.q** in Fig.17.
- Z_7 represents the function of the Switch device to which the requests are sent from the causal devices **zer.q** and **gen.q** inside the causal device **crr.q** in Fig.17.
- Z_8 represents the function of the Switch device inside the **srv.s** device in Fig.17.
- Z_9 represents the function of the comprise devices **srv.qs** and **ofr.qs** in Fig.17.

Eleven types of tokens are used in the model:

- Tokens of type α represent the requests. In the initial time moment of the GN functioning, token α stays in place l_1 with initial characteristic "formula for generating the offered flow of requests to the queuing system".
- Token of type β stays in place l_{blcqs} in the initial time moment with initial characteristic "initial values of $Y_{blc.qs}, P_{blc.qs}, F_{blc.qs}, T_{blc.qs}, N_{blc.qs}$". It is used to accumulate data about the **blc.qs** device.

- Token of type γ stays in place l_{parq} in the initial time moment with initial characteristic "initial values of $Y_{par.q}, P_{par.q}, F_{par.q}, T_{par.q}, N_{par.q}$". It is used to accumulate data about the **par.q** device. The discipline of service of the requests can be specified in this initial characteristic. Here, we consider only FIFO discipline of service of the requests.

- Token of type δ stays in place l_{zerq} in the initial time moment with initial characteristic "initial values of $Y_{zer.q}, P_{zer.}, F_{zer.q}, T_{zer.q}, N_{zer.q}$". It is used to accumulate data about the **zer.q** device.

- Token of type ϵ stays in place l_{genq} in the initial time moment with initial characteristic "initial values of $Y_{gen.q}, P_{gen.q}, F_{gen.q}, T_{gen.q}, N_{gen.q}$". It is used to accumulate data about the **gen.q** device.

- Token of type ζ stays in place l_{srvq} in the initial time moment with initial characteristic "initial values of $Y_{srv.q}, P_{srv.q}, F_{srv.q}, T_{srv.q}, N_{srv.q}$". It is used to accumulate data about the **srv.q** device.

- Token of type η stays in place l_{crrq} in the initial time moment with initial characteristic "initial values of $Y_{crr.q}, P_{crr.q}, F_{crr.q}, T_{crr.q}, N_{crr.q}$". It is used to accumulate data about the **crr.q** device.

- Token of type θ stays in place l_{pars} in the initial time moment with initial characteristic "initial values of $Y_{par.s}, P_{par.s}, F_{par.s}, T_{par.s}, N_{par.s}$". It is used to accumulate data about the **par.s** device.

- Token of type κ stays in place l_{crrs} in the initial time moment with initial characteristic "initial values of $Y_{crr.s}, P_{crr.s}, F_{crr.s}, T_{crr.s}, N_{crr.s}$". It is used to accumulate data about the **crr.s** device.

- Token of type λ stays in place l_{ofrqs} in the initial time moment with initial characteristic "initial values of $Y_{ofr.qs}, P_{ofr.qs}, F_{ofr.qs}, T_{ofr.qs}, N_{ofr.qs}$". It is used to accumulate data about the **ofr.qs** device.

- Token of type μ stays in place l_{srvqs} in the initial time moment with initial characteristic "initial values of $Y_{srv.qs}, P_{srv.qs}, F_{srv.qs}, T_{srv.qs}, N_{srv.qs}$". It is used to accumulate data about the **srv.qs** device.

The formal description of the GN transitions can be found in [Andonov et al, 2020].

Conclusion

As a result of the presented research on the conceptual modelling of queuing systems in service networks, two approaches have been developed – Service Systems Theory approach and GNs approach. The comparison of the two approaches shows that depending on the purpose of the modelling one or the other may give better results. Furthemore, the proposed GNs representation of the elements of Service Systems Theory allows easier construction of GNs conceptual models based on Service Systems Theory and vice versa.

The large number of conceptual models of queuing systems that have been developed as a result of our research has lead to the rise of another problem, i.e., which one of the models to choose. This problem is partially addressed in the paper [Andonov et al, 2020b], where a general scheme for conceptual optimization of GN models is proposed based on the indicators for complexity of GNs. Also there, the conceptual optmization scheme is applied to a GN model of a queuing system.

In [Andonov et al, 2019], a conceptual model of a queuing system based on Service Systems Theory is included in a conceptual model of overall telecommunication system. Analytical expressions for the important parameters of the queuing system are derived.

In [Andonov et al, 2019c], an analytical model of overall telecommunication system with queuing is constructed using the conceptual model based on Service Systems Theory.

In [Andonov et al, 2020c], a GN model of overall telecommunication system with queuing is described. One of the GN models of a queuing system(corresponfing to the detailed representation) is included in the model.

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Bibliography

[Andonov & Atanassov, 2013] Andonov, V., Atanassov, K. : Generalized nets with characteristics of the places. Compt. rend. Acad. bulg. Sci., Vol. 66, 2013, No. 12, 1673ï£¡-1680.

[Andonov et al, 2018] Andonov, V., Poryazov, S., Otsetova, A., Saranova, E., Generalized net model of a part of overall telecommunication system with a queue in the Switching stage. Proc. of the 16th International Workshop on Generalized Nets, Sofia, 9-10 February, 2018, 75–84.

[Andonov et al, 2019] Andonov, V., Poryazov, S., Otsetova, A., Saranova, E.: A Queue in Overall Telecommunication System with Quality of Service Guarantees. In: Poulkov V. (eds) Future Access Enablers for Ubiquitous and Intelligent Infrastructures. FABULOUS 2019. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 283, Springer, Cham, 2019, 243–262.

[Andonov et al, 2019a] Andonov, V., Poryazov, S., Saranova, E.: Generralized net representations of elements of service systems theory. Advanced studies in contemporary mathematics, 29, 2019, No 2, 179–189.

[Andonov et al, 2019b] Andonov, V., Poryazov, S., Saranova, E.: Extended conceptual models of queuing systems. International Journal "Information Models and Analyses", Vol. 8, No 3, 2019, 231–243.

[Andonov et al, 2019c] Andonov, V., Poryazov, S., Saranova, E.: Analytical model of overall telecommunication system with queuing. International Journal "Information Models and Analyses", Vol. 8, No 3, 2019, 212–230.

[Andonov et al, 2020] Andonov, V., Poryazov, S., Saranova, E.: Generalized net representations of control structures in service systems theory. Advanced Studied in Contemporary Mathematics (Kyungshang), 30 (1), 2020, 49–60.

[Andonov et al, 2020a] Andonov, V., Poryazov, S., Saranova, E.: Generalized net representations of the causal structure of a queuing system. Proc. of the 2020 IEEE 10th International Conference on Intelligent Systems (IS), Varna, Bulgaria, 2020, 80–86.

[Andonov et al, 2020b] Andonov, V., Poryazov, S., Saranova, E.: Conceptual optimization of a generalized net model of a queuing system. In: Proc. of the 2020 Federated Conference on Computer Science and Information Systems, 223–226.

[Andonov et al, 2020c] Andonov, V., Poryazov, S., Saranova, E.: Generalized Net Model of Overall Telecommunication System with Queueing. In Atanassov K.T. et al. (Eds.): Advances and New Developments in Fuzzy Logic and Technology - Selected Papers from IWIFSGN'2019 - The Eighteenth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets, October 24-25, 2019 in Warsaw, Poland, Advances in Intelligent Systems and Computing, Springer Verlag, 2020. (in press)

[Atanassov, 2007] Atanassov, K.: On Generalized Nets Theory. Prof. M. Drinov Academic Publ. House, Sofia, Bulgaria, 2007.

[Atanassov, 2013] Atanassov, K., Szmidt, E., Kacprzyk, J.: On Intuitionistic Fuzzy Pairs. Notes on Intuitionistic Fuzzy Sets, 19(3), 2013, 1–13.

[Erlang, 1917] Erlang, A.: Solution of some Problems in the Theory of Probabilities of Significance in Automatic Telephone Exchanges. Elektrotkeknikeren, 13: 5, 1917.

[Gupta & Aurora, 2018] Gupta, Sh., Aurora, S. : Queuing Systems in Cloud Services Management: A Survey. International Journal of Pure and Applied Mathematics, Volume 119, No. 12, 2018, 12741-12753.

[Gatnau et al, 2013] Gatnau, M., Catania, D. , Cattoni, A. F., Ashta, J. S., Mogensen, P.: A multi-QoS aggregation mechanism for improved fairness in WLAN. In Vehicular Technology Conference (VTC Fall), 2013 IEEE 78th, 2013, 1–5.

[ITU-T, 2017] ITU-T Recommendation ITU-T P.10/G.100 (11/2017). Vocabulary for performance, quality of service and quality of experience.

[ITU-T E.501,] ITU-T E.501 (05/97): ITU-T E.501 (05/97): Estimation of traffic offered in the network.

[Iversen, 2010] Iversen, V.B.: Teletraffic Theory and Network Planning, Technical University of Denmark, 2010 Textbook. Available: http://oldwww.com.dtu.dk/teletraffic/handbook/telenook.pdf

[Kleinrock, 1975] Kleinrock, L.: Queueing Systems, Volume 1: Theory, 1975.

[Larsson, 2014] Larsson, C., Design of Modern Communication Networks: Methods and Applications. Elsevier 2014, ISBN: 978-0-12-407238-1, pp.446.

[Otsetova, 2016] Otsetova, A.: Validation of the Logistics Service Quality Scale in Bulgarian Courier Sector. Management and Education, Vol. XII, (1) 2016, 46-52.

[Poryazov & Atanassov, 1997] Poryazov, S., Atanassov, K.: Generalized Net Subscribers' Traffic Model of Communication Switching Systems. Journal on Advances in Modelling & Analysis, Vol. 37, 1997, No. 1-2, 27-35.

[Poryazov & Saranova, 2012] Poryazov, S., Saranova, E.: Models of Telecommunication Networks with Virtual Channel Switching and Applications. Academic Publishing House "Prof. M. Drinov", Sofia, 2012.

[Poryazov et al, 2018a] Poryazov, S., Andonov, V., Saranova, E.: Comparison of Four Conceptual Models of a Queuing System in Service Networks. Proc. of the 26th National conference with international participation TELECOM 2018, Sofia, 25-26 October, 71-77, 2018.

[Poryazov et al, 2018b] Poryazov, S., Saranova, E., Ganchev, I.: Scalable traffic quality and system efficiency indicators towards overall telecommunication system's QoE management. In: I. Ganchev, R.van der Mei, H.van den Berg, Eds., Autonomous Control for a Reliable Internet of Services. State-of-the-Art Survey, LN in Computer Science, vol. 10768, Springer, Cham, 2018, 81-103.

[Poryazov et al,2020a] Poryazov, S., Andonov, V., Saranova, E.: Traffic quality aggregations of a queuing system. In proc. of the 2020 IEEE 10th International Conference on Intelligent Systems (IS), Varna, Bulgaria, 2020, 102-110.

[Poryazov et al, 2020b] Poryazov, S., Andonov, V., Saranova, E.: Methods for Modelling of Overall Telecommunication Systems. Research in Computer Science in the Bulgarian Academy of Sciences, Studies in Computational Intelligence, 2020. (in press)

[Robinson et al, 2011] Robinson, S., Brooks, B., Kotiadis, K., Van Der Zee, D.: Conceptual Modeling for Discrete-Event Simulation. Taylor and Francis Group, LLC, CRC Press, 2011, ISBN -13: 978-1-4398-1038-5 (Ebook-PDF) 527 pages.

[Tomov et al, 2018] Tomov, Zh., Krawczak, M., Andonov, V., Dimitrov, E., Atanassov, K.: Generalized net models of queueing disciplines in finite buffer queueing systems. Proceedings of the 16th International Workshop on Generalized Nets, Sofia, 10 February, 2018, 1-9.

[Tomov et al, 2019] Tomov, Zh., Krawczak, M., Andonov, V., Atanassov, K., Simeonov, S.: Generalized net models of queueing disciplines in finite buffer queueing systems with intuitionistic fuzzy evaluations of the tasks. Notes on Intuitionistic Fuzzy Sets, Vol 25, 2019, No 2, 115-122.

[Varela et al, 2015] Varela, M., Zwickl, P., Reichl, P., Xie, M., Schulzrinne, H.:From service level agreements (SLA) to experience level agreements (ELA): The challenges of selling QoE to the user. IEEE ICCW, 2015, 1741-1746.

[Zheng et al, 2011] Zheng, H., Yang, J., Zhao, W.: General probability distribution-based QoS analysis for web service composition. International Symposium on Web Intelligent Systems & Services. D.K.W. Chiu et al, Eds., WISE 2010 Workshops, LNCS 6724, Springer-Verlag, 2011, 98-111.

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