Abstract. This paper describes the transient analysis component for deterministic and stochastic Petri nets which has recently been added to the software package TimeNET. The technique is based on the derivation of state equations by the method of supplementary variables. The system of equations consists of partial and ordinary differential equations which are combined with initial and boundary conditions. Algorithms for the numerical analysis of the equations are presented. Emphasis is put on implementation aspects. Different cases are identified for which different variants of the algorithms can be used. The computational complexity is investigated by asymptotical expressions and by measurements. Several examples are used in order to illustrate the modeling process and transient analysis with TimeNET.

1 Introduction

Stochastic Petri nets (SPNs) are well suited for the model-based performance and dependability evaluation. Most commonly, the firing times of the transitions are exponentially distributed, leading to an underlying continuous-time Markov chain. In order to increase the modeling power, several classes of non-Markovian SPNs were defined, in which the transitions may fire after a non-exponentially distributed firing time.

A particular case of non-Markovian SPNs is the class of deterministic and stochastic Petri nets (DSPNs), where in each marking at most one transition is allowed to have a deterministic firing time. A stationary analysis method for DSPNs was presented in [1] and the transient analysis was addressed in [4]. Both methods are based on an underlying Markov regenerative process. Although general formulas were derived for the transient analysis in [4], their numerical solution poses problems and is still under investigation. Special cases in which a numerical analysis is possible are considered in [14, 15, 16].

An alternate method is to use supplementary variables [7] for the derivation of state equations which describe the dynamic behavior of the DSPN. In [10] it was shown how this approach can be used for the stationary analysis and in [8] it was shown how it can be used for the transient analysis. In [11] the two approaches based on Markov regenerative theory and on supplementary variables are compared. The transient analysis method for DSPNs based on supplementary variables has been implemented as a general purpose algorithm
and has been added to the software package *TimeNET*. *TimeNET* [9] provides several specialized components for the analysis and simulation of non-Markovian SPNs.

This paper describes the transient analysis component of *TimeNET*. Implementation aspects and different variants of the algorithms are discussed. The remainder is organized as follows. In Sec. 2 the considered class of SPNs is defined. Section 3 contains a general description of the software package *TimeNET* and gives a comparison with other SPN software packages. In Sec. 4 the mathematical background taken from [8] is reviewed. Section 5 discusses several variants of the numerical analysis algorithms. Section 6 illustrates the modeling process and transient analysis with *TimeNET*. Section 7 gives measurements of the costs of the different algorithms. Concluding remarks are given in Sec. 8.

2 Deterministic and Stochastic Petri Nets

We consider the class of DSPNs as defined in [1]. Net primitives are *places*, *transitions*, and *arcs*. Places may contain undistinguishable *tokens*. Transitions can be *immediate*, *deterministic*, or *exponential*. The firing rules and policies are defined as in [1]. In particular, it is assumed that all transitions have the firing policy *race with enabling memory* (i.e., the age memory of a transition is set to zero, when it fires or is preempted). See [2] for other firing policies.

Depending on the structure of the DSPN different transient solution techniques are used. Three cases are distinguished: 1) the net does not contain any deterministic transitions, 2) the deterministic transitions fire periodically at previously known instants of time, 3) the deterministic transitions fire at random time instants. As structural restriction we require that in each marking at most one deterministic transition is enabled. For case 3) we also need that deterministic transitions may not be initially enabled.

3 The Software Environment *TimeNET*

Several software packages have been developed for the modeling with stochastic Petri nets (SPNs) [3, 6, 18, 13, 9]. *TimeNET (Timed Net Evaluation Tool)* [9] was developed at the Technische Universität Berlin and is especially designed for non-Markovian SPNs. In the following we give a comparison of *TimeNET* with other tools.

*GreatSPN* [3] provides a graphical user interface (GUI) for interactively editing and validating the model. Transient and stationary numerical analysis is possible, if all transition firing times are exponentially distributed (Markovian SPNs). Simulation is provided otherwise. Furthermore, *GreatSPN* supports SPNs with colored tokens and provides several qualitative analysis and operational analysis algorithms. *SPNP* [6] is also designed for the transient and stationary analysis of Markovian SPNs. General reward specifications can be defined and computed with *SPNP*. *UltraSAN* [18] is another GUI-based tool for