Modelling and Control the Reliability of the Multiagent Control Systems

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Abstract: The multiagent systems are the new structure of the decentralized control system, with special attributes like autonomy, adaptivity and communication. These systemes begin used more frequently on the field of the automatic control too. Hence, is necessary redard to theirs reliability. This article briefly describes methods for reliability modeling, evaluation and its hierarchical control of the multiagent control systems.

Keywords: Agent, hybrid system, reliability

1 Introduction to the Multiagent System in Control

The multiagent systems are the new structure of decentralized control system, with special attributes like autonomy, an adaptivity and communication. The multiagent system consists of many individual agent, which communicated among themself. There is not general valid answer for the question: 'What is agent?' There are many different definitions of this term.

By [1, 2] agent may be represented two different types. The weak and strong agent.

The definition of weak the agent is:

Hardware or software system, which fulfill following conditions:

- autonomity – agent working without direct human intervention or another intervention. The agent had control of its action, and its inner world
- social skills – agent interaction with another agent or a human by special communication language
- Reactivity – agent influents its environments (the environment may be represented by really world, internet, users with special visual interface etc.)
- pro-activity – work of the agent is not simple respond to environment conditions.

The definition of the strong agent is:

The agent includes above mentioned condition and the agent has special attributes which has represented mental and emotion status like knowledge, religion, contemplation. The agents fulfill following conditions:

- Autonomity – the same like a weak agent, but the environment could not be simply described.
- Cooperation – this is the group of the social skills that agent use for communicating with another agent or human by a special communication language. Cooperation is one of the most important attribute of multiagent system. Agent could cooperation with another agent without communication.
- Learning – if agent is able to reacte on dynamic undetermined environment and also able to work on this environment than agent has to have specific factor of learning, which describe communication between agent and its environment. The learning may increase quality of agent's behavior in environment.

By [3] agent must fulfill two of above mentioned previsions conditions.

1.1 Baseline Architecture of the Multiagent Systems

By [1] architecture of the multiagent system is:

Special methodology of the creating agent. Every agent may be decomposed on a structure, that consist of collection of parts, collection of object, and collection interaction of object

There are exist four different architecture in the multiagent system which are as follows:

- deliberative architecture (classic access) – Think hard, than act
- reactive architecture (alternative access) – Don't think, act
- hybrid architecture – Think and act independently, in parallel
- behavior based – Think the way you act

1.1.2 Multiagent System

In multiagent system every agent which is in environment is simulate like entity with goal, action and knowledge. In general, in multiagent system exists direct interaction between agent and environments and among agents.

The group of agents may be homogeneous or heterogeneous. If the agents have the equivalent attributes than agents are in homogeneous group. If the agents have different attributes than agents are in heterogeneous group. The degree heterogeneity of agent depends on a concept of fulfilment task. If the degree is very high than task will finished without cooperation. If the degree is insufficient than the cooperation is necessary. In general heterogeneous in multiagents causes increase in solving of task. In the figure 1 is shown general diagram of multiagent system, which communication between agent and environments and among agents.

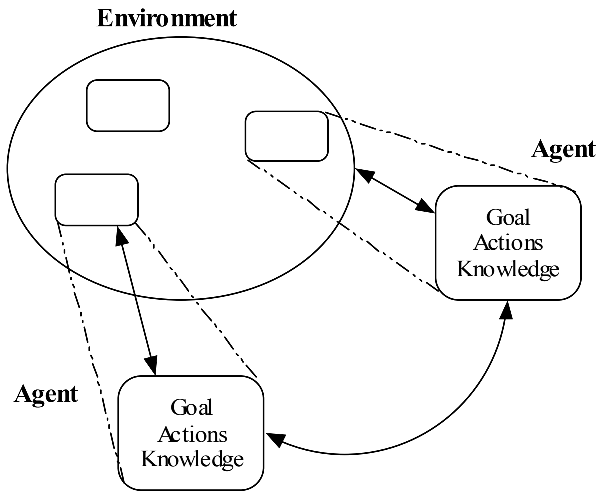

Figure 1
General diagram of multiagent system

By [5] the characteristic of Multiagent systems are follows:

- each agent has incomplete information or capabilities for solving the problem and, thus has a limited viewpoint,
- there is no system global control,
- data are decentralized,
- computation is asynchronous.

2 Methods for Reliability Evaluation of the Multiagent Systems

The most used tools for the reliability modelling and for the quantitative determination of the system reliability are:

- Markov models [7],
- State space method [6],

- Fault Trees [8, 9],
- Reliability Block Diagrams [6],
- Bayesian networks [10, 11],
- Petri nets in combination with Monte Carlo simulation [7, 12, 13].

Some methods are practically unusable or usable with high difficulty. For example, for the state space method is based on the enumeration of all possible states of the modelled system and to classify them as 'failure state' or 'functional state' [6]. This requirement for creation the model of the system as multiagent control system is practically unrealizable in regard of its complexity. There are few types of the methods more suitable for modeling the reliability of the multiagent control systems. Two of them as Bayesian networks and Petri Nets will be described in next parts of the paper.

2.1 Bayesian Networks

Bayesian networks (further only BN) are a form of probabilistic graphical model. More precisely is defined as [10] a set of nodes (random variables) and directed edges between them. Random variables and directed edges form directed acyclic graph and holds:

- each variable has a finite set of mutually exclusive states,
- to each variable A with parents B1,…,Bn there is attached a conditional probability table P(A | B1,…,Bn).

There are few different types of the BNs [11] as dynamic BNs, continuous BNs, etc. Each random variable can represent one part of the multiagent control system (one agent as controller, actuator, etc.). Interactions among agents are represented by directed arcs which allow describing the direction of the interactions (communication from controller to actuator, etc.). Features of the extended BNs, which are mentioned above, make this tool more useable for reliability modelling of the multiagent control systems. In Figure 2 there is shown simple example of the Bayesian network with different interactions among each node.

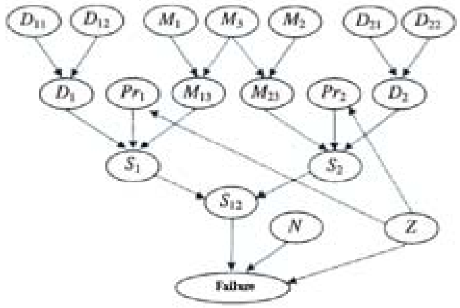

Figure 2
Bayesian network

2.2 Petri Nets

Petri nets (further only PN) is a tool which can be widely used for modelling different tasks as control systems, networks, system reliability estimation, etc. Hence, there are few types of PN which could be used for modelling and solving different systems and problems.

The system reliability assessment can be ensured thanks to *stochastic Petri Nets* (SPN) [10, 12]. *SPN* is a special case of timed PN [12] where the transition firing times are considered as random variables. The firing time for each transition is determined by this random variable. When firing time is exponentially distributed then the marking process is mapped into a continuous time Markov model [14]. Thus, in SPN transition wait for firing, after its enable is non-fixed time but time interval is determined by random variable with exponentially distribution. An example of the system failure (10) / repair (01), with failure rate λ, is shown in Figure 10. There is also shown the equivalent continuous time Markov model.

The Stochastic Petri Nets are a dynamic modelling method (tool) for system reliability modelling.

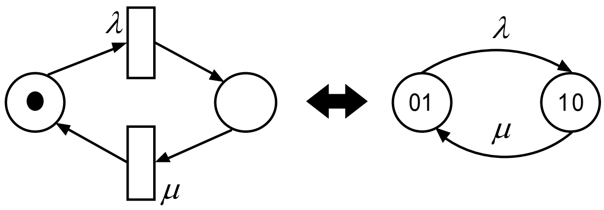

Figure 3
SPN failure / repair model and its continuous time Markov model equivalent

In general PN are very useful to model interactions among the each part the modelled system. In the case of multiagent systems the PN in combination with

ML language could be used to model the communication among agents too. This feature computes not only with network failure probability but it allows simulating real communication by defining the specified communication protocols, etc.

Reliability modelling of the multiagent control system using SPN [15] can be provided as follows:

1 System model preparation –modelling each part of the system (agents) and interactions among them.

2 Testing the system – provide the test of the modelled system during the specified time interval which can be signed as statistically significant. The aim of the testing is to determine how many times the system has operated successfully and how many times the system was unable to operate in the required conditions (system failed).

3 The results of the test are two sets S and F, where S is the set of the system success and F is set of the system failures.

4 Then, the reliability of the modelled system is given by:

$$R = \frac{S}{S + F} \tag{1}$$

or could be applied statistical method, as Monte Carlo smulation, to determine reliability with defined exactness, to obtained results.

3 Hierarchical Reliability Control of the Multiagent Hybrid Systems

Reliability of decentralized hybrid systems can be improved by hierarchical control. Each subsystem (of decentralized system) is considered as a single agent. There is decision unit which control reliability of whole system. Control of reliability is control of Markov process by control signal, which is output from decision unit.

There are three levels of control. System is controlled by local continuous regulator on the first level. The second level of control has set of states *S*. Each state represents function of regulators, where exist matrix of changes rate *P,* which is built from knowledge of system dynamic. Third level is represented by decision unit, which generates control signal. This signal could be solution of optimalization task.

Main characteristic, which let us to be able to control Markov process, is dependency components of matrix *P* on variables, they can be changed (for example repair rate $\mu(t)$).

3.1 Reliability Control by Using of the Optimal Control Theory

Let us suppose that our subsystem (agent) has *s* states. $p_k(t)$, where *k=1,2,..,s,* is probability - system is at time *t* in state *k*. Coefficients μ and λ can in general be functions of time, where service rate $\mu(t)$ is control signal. Kolmogorov equations for this case are:

$$\dot{p}_1(t) = -\lambda(t)p_1(t) + \mu(t)p_2(t)$$

$$\dot{p}_k(t) = \lambda(t)p_{k-1}(t) - [\lambda(t) + \mu(t)]p_k(t) + \mu(t)p_{k+1}(t)$$
$$k = 2,3,...,s-1$$

$$\dot{p}_s(t) = \lambda(t)p_{s-1}(t) - \mu(t)p_s(t) \tag{2}$$

These equations (2) can be transferred to matrix shape:

$$\dot{p}(t) = [F\lambda(t) + G\mu(t)]p(t); \quad p(0) = p_0 \tag{3}$$

where *F* and *G* are matrixes of $s \times s$ dimension in answer shape and $\mu(t)$ and $\lambda(t)$ are scalars.

If value of failure rate $\lambda(t)$ is invariable (it is mean that $\lambda(t) = \lambda_0$), than we obtain for (3):

$$\dot{p}(t) = \lambda_0 Fp(t) + \mu(t)Gp(t) \tag{4}$$

From this equation (4) results:

$$\mu(t)Gp(t) \equiv f(\mu(t), p(t)) \tag{5}$$

Because function *f* is nonlinear function of μ and *p*, it is important to linearize it in its work area in some nominal values μ^* and $p^*(t)$:

$$f(\mu(t), p(t)) = f(\mu^*, p^*(t))_{\substack{\mu(t)=\mu^* \\ p(t)=p^*(t)}} + \frac{\partial f}{\partial \mu}_{p(t)=p^*(t)} \Delta\mu(t) + \frac{\partial f}{\partial p}_{\mu(t)=\mu^*} \Delta p(t)$$

where

$$\frac{\partial f}{\partial \mu} = Gp \; ; \quad \frac{\partial f}{\partial p} = \mu G \tag{6}$$

From presented information (2)-(6) we can derivate equation:

$$\Delta \dot{p}(t) = \lambda_0 F + \Delta p(t) + Gp^*(t)\Delta\mu(t) + \mu^* G\Delta p(t)$$

or:

$$\Delta \dot{p}(t) = [\lambda_0 F + \mu^* G]\Delta p(t) + Gp^*(t)\Delta\mu(t)$$

This equation can be rewrite to shape of:

$$\Delta \dot{p}(t) = A\Delta p(t) + B(t)\Delta\mu(t) \tag{7}$$

where

$$A = [\lambda_0 F + \mu^* G]; \quad B(t) = Gp^*(t)$$

This problem can be understand as problem of optimal control, where our criteria function is

$$J = \frac{1}{2}\int_0^T (\Delta p^T(t)Q\Delta p(t) + \Delta\mu^T(t)R\Delta\mu(t))dt \tag{8}$$

where change of repair rate $\Delta\mu(t)$ is control signal and it can be solved by using equation from theory of optimal and adaptive control:

$$\Delta\mu(t) = -R^{-1}B^T(t)K(t)\Delta p(t) \tag{9}$$

where $K(t)$ is solution of Riccati equation.

Operating of such designed control algorithm of reliability (Markov process) can be described by follow: there are given nominal trajectories of probability vector $p^*(t)$ and nominal value of repair rate μ^* (for given time interval). If fault rate changes its value ($\lambda = \lambda_0 + \Delta\lambda$) than in control system (which is proceeded) is resolved redundant control $\Delta\mu(t)$ and it increments its value to nominal repair rate μ^*.

In Figure 4 there is shown block scheme of reliability control of multiagent system by using theory of optimal control.

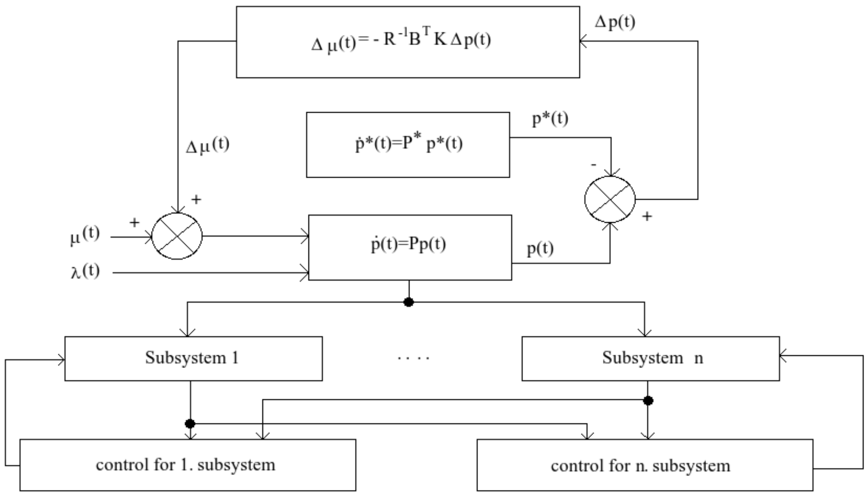

Figure 4
Hierarchical control

Conclusion

This article gives short summary look about:

- what are multiagent hybrid systems,
- how to model reliability in these systems,
- and short possibility how to control reliability by using theory of optimal control.

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