Markov Model of FPGA Resources as a Service Considering Hardware Failures

Inna Kolesnyk[1], Vitaliy Kulanov[2], Artem Perepelitsyn[3]

National Aerospace University "KhAI", Chkalov str. 17, 61070 Kharkov, Ukraine.
[1] i.zarizenko@csn.khai.edu
[2] v.kulanov@csn.khai.edu
[3] a.perepelitsyn@csn.khai.edu

Abstract. The FaaS architecture is analyzed. Based on information on the structure and principles of the architecture FaaS the structural reliability diagram is developed. Markov model for structural reliability diagram considering possible hardware failures is presented. The expert evaluation of intensities of failure and maintenance is proposed. The reliability evaluation of FaaS based on obtained results is performed.

Keywords: Markov model, Programmable Logic, FPGA, FaaS, Hardware Failures, Computer System

1 Introduction

The popularity of cloud services as well as the current level of technology development makes it possible to provide resources of programmable logic integrated circuits to an end user via the Internet. In the work [1], a solution was proposed to use FPGA as a Service (FaaS). The proposed architecture can be recommended for tasks focused on intensive information processing when the requirements for the input and output data streams are not so strict. A resource intensive computational task was performed to test the proposed approach and it consisted of searching polynomials for shift registers with nonlinear feedback of the second degree by the "brute force" method [2]. This has saved time and resources for obtaining final results.

One of the main requirements for cloud services is their high availability achieved by reducing and managing failures as well as minimizing planned downtime time. Classical models of the reliability of data storage, built on the basis of Markov chains in continuous time, the models are considered in a number of works [3, 4]. Markov models retain a significant advantage in productivity and speed of calculations (up to 150 times, see [5]) in comparison with full-scale imitation modeling.

Disadvantages of classical models with one-dimensional Markov chains without memory are described in detail in a widely known paper [6]. In [7, 8], the Markov model of the availability of SBC based on the analysis of hardware and software failures was developed and investigated.

Thus, the goal of the study is to improve the systems reliability implementing FaaS with the provision of FPGA resources for user tasks. To achieve this goal it is necessary to solve the problem of formalizing actions order to evaluate the reliability of these systems based on Markov model, as well as the practical application of the proposed method.

2 Assessment of Reliability of FaaS based on Markov Model, Considering Possible Hardware Failures

The FaaS architecture is a complex multi-level and multi-component hardware and software system. The FaaS infrastructure components are conditionally divided into two parts: client and server (Figure 1). The model of server part with FPGA boards will be considered.

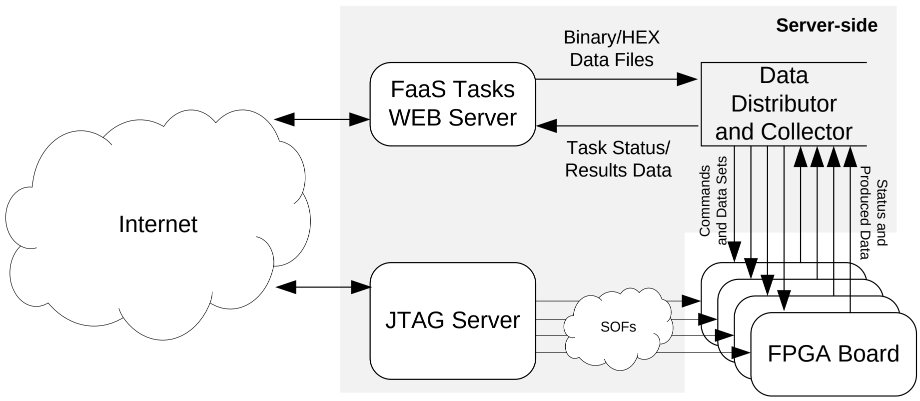

Fig. 1. FPGA architecture as a service

The FaaS architecture assumes the usage of multiple components in the server part. The use of redundancy is advisable for such systems, because their individual nodes efficiency determines the entire system operability. In case of failure of one system component (the reservation backup of which is provided), the system remains operational. Such degradation changes in the system affect the probability of safe operation at any given time.

The main functional elements of the system are the server part components and they are subject to failure which may also be caused by hardware defects. Failure of system elements is a random and independent event.

The Markov model is a convenient tool for describing the processes of system components failure and recovery with the described properties. Since the basic components of FaaS are a priori known, it is possible to generalize the process of evaluating the reliability indicators these systems using Markov models.

To evaluate the reliability of the FaaS architecture hardware, the following sequence of actions is suggested:

- identify the set of hardware components that make up FaaS;
- determine the availability and type of reservation in the architecture in question;
- build a structural scheme of reliability for a set of components;
- determine the failure rates and recovery for each system component;
- considering the CLS, construct the system state graph;
- using Markov models mathematical apparatus numerically determine the system reliability indicators.

To build the FPGA infrastructure as a service, we will simulate the components of the server part using Markov chains.

We analyze the redundant computing system FaaS infrastructure designed to perform service functions by a client request, giving it access to certain resources and managing programmable logic integrated circuits (FPGAs) that can be programmed by the user request via the Internet.

The FaaS includes combination of programmable logic and classical computer components that required to organize the service itself.

The system's performance in the above case is presented in accordance with the structural reliability scheme (Figure 2).

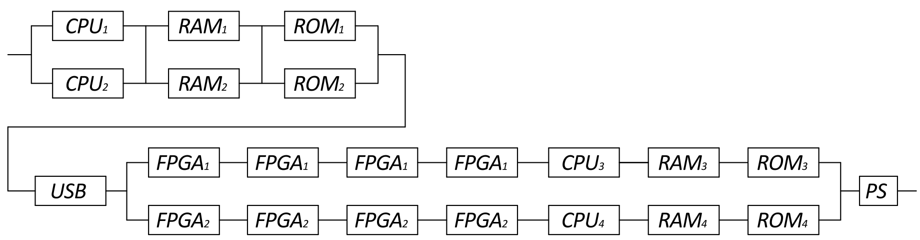

Fig. 2. Structural diagram of reliability the FPGA system as a service

The block diagram used to describe the system reliability is a combination of serial and parallel connections. All components of the system operate simultaneously. Failure of a main system element does not affect the system's operability according to system failure definition. It remains in working order, since the back-up elements provide the functionality. The main elements are: processor (CPU), random access memory (RAM), permanent storage (ROM), which must ensure the system functioning. Each block in the chain is duplicated.

In these FaaS architecture each FPGA chip implements unique functions provided by service user. To organize the function properly of this computer system, all FPGAs involved in the structural diagram are connected in series.

If the user wants to implement on-chip redundancy he can program FPGA using fault tolerant approach, but this case will be considered separately.

3 Development of the Markov model FPGA as a service

During the process of using the Markov analysis apparatus, following computational difficulties can arise: the growth is simple, the sparseness of the matrix of the intensities of the transitions between the states of the Markov model (MM) and its rigidity. Since one of the main process requirements is assessing the reliability of the aircraft and ensuring high accuracy of the results, it is necessary to consider each feature of the Markov analysis apparatus at all stages of the aircraft readiness assessment. Our task is to minimize the probability of its occurrence, and in case of occurrence, identify it in a timely manner and take measures to prevent the elimination of consequences.

Consider the computer system FPGA as a service as a redundant system with parallel connection of backup system equipment. In this scheme, all elements of backup equipment samples have different failure rates. To this variant of reservation, the rule to determine the reliability of parallel independent elements is applicable.

To evaluate the reliability of recoverable objects, the differential equations method is applied. It is based on the assumption of exponential time distributions between failures (operating time) and recovery time.

To apply this method, we need to have a mathematical model for the set of possible states of the system S = {S1, S2, ..., Sn}, in which it can be located in the event of system failures and failures.

From time to time, the system S jumps from one state to another under the influence of failures and restoration of its individual elements. When analyzing the behavior of the system in time during wear, it is convenient to use a state graph on the basis of which we obtain a system of equations. We will illustrate the graph of the state reflecting the dynamics of the system.

The dynamics of the system can be reflected by changing the states of the elements. Each of the elements can be in one of three states:

1 – mode of operation;

2 – mode of the main element failure;

3 – mode of the backup element failure.

Then the set of states of the system has the form:

S0 – it functions;

S1 – Element CPU1 has failed, the system operates in standby mode;

S2 – failed element RAM 1, the system operates in standby mode;

S3 – ROM 1 failed, the system operates in standby mode;

S4 – FPGA1..4 failed, the system operates in standby mode;

S5 – the elements CPU1 and RAM1 failed, the system operates in standby mode;

S6 – the elements CPU1 and ROM1 failed, the system operates in standby mode;

S7 – the elements of CPU1 and FPGA1,4 failed, the system operates in standby mode;

S8 – elements of RAM1 and ROM1 failed, the system operates in standby mode;

S9 – the elements of RAM1 and FPGA1,4 failed, the system operates in standby mode;

S10 – the elements of ROM1 and FPGA1,4 failed, the system operates in standby mode;

S11 – the elements CPU1, RAM1 and ROM1 failed, the system operates in the standby mode;

S12 – elements of CPU1, RAM1 and FPGA1,4 failed, the system operates in standby mode;

S13 – the elements CPU1, ROM1 and FPGA1.4 failed, the system operates in standby mode;

S14 – elements of RAM1, ROM1 and FPGA1,4 failed, the system operates in standby mode;

S15 – the elements CPU1, RAM1, ROM1 and FPGA1.4 failed, the system operates in a redundant mode;

S16 – the system is inoperable.

The illustrated graph of the state reflecting the dynamics of the system is provided in figure 3.

Based of result of solving the system of differential equations in the computer mathematics system Mathcad the curve of failure-free state probability of the proposed FaaS architecture was created. The assessment result are shown in figure 4.

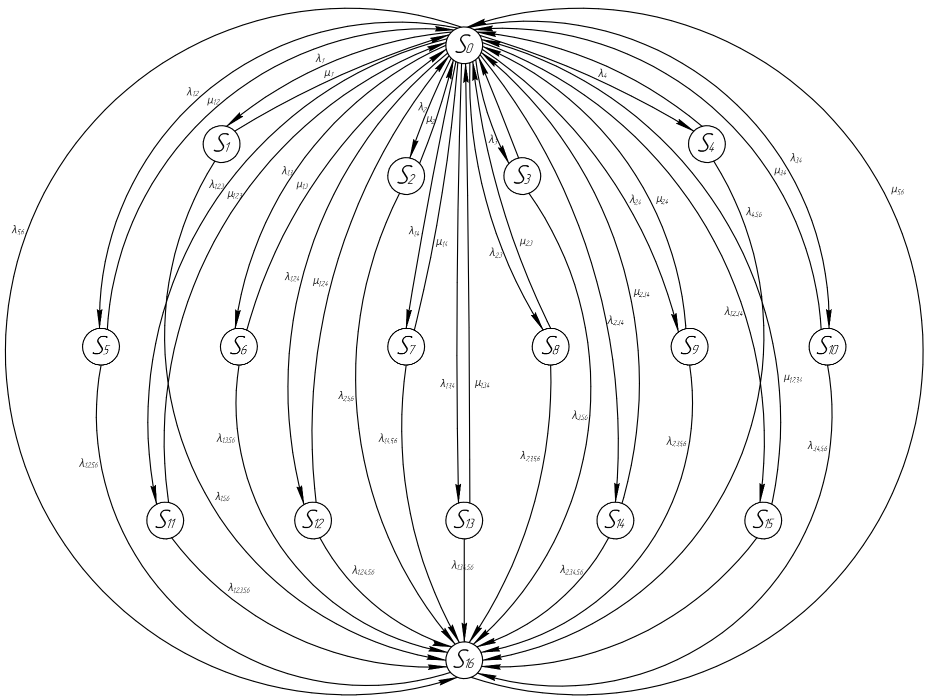

Fig. 3. The Markov graph, which is part of the model for states

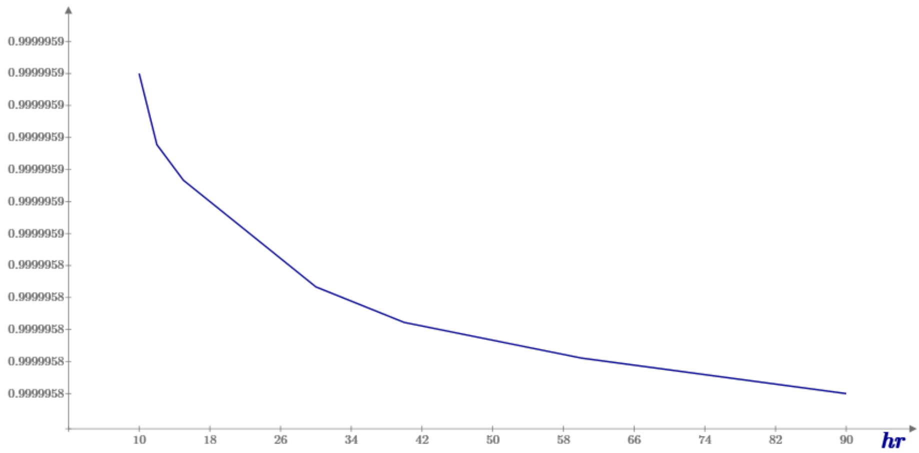

Fig. 4. Diagram of failure-free state probability for proposed FaaS architecture

4 Conclusion

In this paper following results were achieved: a method for assessing the FaaS reliability based on the Markov model, in a view of possible hardware failures, considering the order of finding failure rates and restoring parts of the system, and practical implementation of the proposed method for a specific implementation of FaaS.

Within the framework of practical implementation, a computer system was simulated on the basis of continuous Markov chains. When assessing the reliability of complex redundant and recoverable systems, the Markov chain method leads to complex solutions because of the large number of states.

Based on the marked state graph of the system, i.e. graph of transitions, in which the intensities of all transitions are known, it is possible to determine the probabilities of these states as a function of time.

Based on the graph, the probability of the system state was determined for various parameters λ and μ. Based on obtained results the reliability evaluation of FaaS was performed.

References

1. Perepelitsyn A.E., Kulanov V.O., Kolesnyk I.N.: Providing of FPGA Resources as a Service: Technologies, Deployment and Case-Study. In: Proceedings of the PhD Symposium at 13th International Conference on ICT in Education, Research, and Industrial Applications co-located with 13th International Conference on ICT in Education, Research, and Industrial Applications, Kiev, pp. 63-68 (2017)
2. Poluyanenko, N.: Development of the search method for non-linear shift registers using hardware, implemented on field programmable gate arrays. In: EUREKA: Physics and Engineering, pp. 53-60 (2017). doi: 10.21303/2461-4262.2017.00271

3. Reibman A. and Trivedi K. S. A.: Transient Analiysis of Comulative Measures of Markov Model Behavior. In: Communications in Statistics-Stochastic Models. pp. 6683-710 (1989)
4. Malhotra M., Trivedi K.S.: Reliability Analysis of Redundant Arrays of Inexpensive Disks. In: Jornal of Parallel and Distributed Computing – Special issue on parallel I/O System. pp. 146-151 (1993)
5. Karmakar P., Gopinath K.: Are Markov Models Effective for Storage Reliability Modeling? In: Arxiv: 1503.07931v1, (2015)
6. Greenan K. M., Plank J. S., Wylie J. J.: Mean Time To Meaningless: MTTDL, Markov models, and Storage System Reliability. In: Proceedings of the 2 nd USENIX conference on Hot topics in storage and file systems. pp. 1-5 (2010)
7. Kharchenko V., Kolisnyk M., Piskachova I., Bardis N.: Markov Model of the Smart Business Center Wired Network Considering Attacks on Software and Hardware Components. In: International journal of computers and communications ISSN: 2074-1294, Volume 10. pp. 113-119 (2016)
8. Kharchenko V., Kolisnyk M., Piskachova I., Bardis N.: Reliability and Security Issues for IoT-Based Smart Business Center: Architecture and Markov Model. In: IEEE; Computer of science, MCSI 2016, Paper ID: 4564699 (2016)
9. Kharchenko V.S., Cherepakhin D.A.: Risk Analysis of Control Systems by Use of QD-diagrams and FMECA-approach. In: Proceedings of 12 th European Conference on Safety and Reliability, Turin, Italy, pp. 16 - 20 (2001).
10. Gorbenko A.V., Kharchenko V.S.: Application of FMEA - technology with reliability and safety of computer networks for critical applications. In: «EUREKA: Physics and Engineering, pp. 53-60 (2017). doi: 10.21303/2461-4262.2017.00271
11. Kilts S.: Advanced FPGA Design. Architecture, Implementation and Optimization. In: The Institute of Electrical and Electronics Engineers, Inc., New York. (2007)
12. Fedukhin A.B., Mukha A.A., Mukha A.A.: FPGA systems as a means of increasing fault tolerance. In: Mathematical machines and systems. pp.198-204 (2010)
13. Hahanov V.I.: Infrastructure Diagnostic Service SoC. In: tutorial of Omsk State University. pp. 74-101 (2008)
14. Yacoub, S.M., Cukic, B., Ammar, H.H.: A scenario-based reliability analysis approach for component-based software. IEEE Transactions on Reliability 53(4), pp. 465–480 (2004)
15. Andryukhin A.I.: Switching modeling and diagnosis of the main fault models of CMOS structures. In: DonNTU. pp. 54-65. (2011)
16. E.J., Kon, Kulagina M.M.: Reliability and diagnostics of components of infocommunication and information management systems. In: tutorial of Perm State Technical University. pp. 167- 179 (2011)
17. Vilkomir, S.A., Parnas, D.L., Mendiratta, V.B., Murphy, E.: Availability evaluation of hardware/software systems with several recovery procedures. In: Proc. 29th Int. Computer Software and Applications Conference (COMPSAC 2005), pp. 473–478. IEEE Computer Society Press, Los Alamitos (2005)
18. Kappler, T., Koziolek, H., Krogmann, K., Reussner, R.: Towards Automatic Construction of Reusable Prediction Models for Component-Based Performance Engineering. In: Proc. Software Engineering 2008 (SE 2008). LNI, vol. 121, February 2008. pp. 140–154. GI (2008)
19. Martin L. Shooman: Reliability of Computer Systems and Networks: Fault Tolerance, Analysis, and Design. pp.446-449 (2002)