

ALGORITHMIZATION OF A STOCHASTIC SWITCHABLE ENVIRONMENT OPERATING IN DISCRETE TIME

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Abstract: The article discussed an algorithmization of the stochastic switchable environment operating in discrete time functioning process. The goal is to create an iterative algorithm for the functioning of such a system with the possibility of node failures. The created algorithm makes it possible to increase the stability of the system and meet the security requirements of specific algorithms for bidirectional interaction for correct collaboration. The modular structure of the stochastic switchable environment operating in discrete time functional process control system software is presented. The data obtained was taken into account when forming databases of network parameters. During the experiments, the effectiveness of the developed special software was proved. To evaluate the effectiveness, data from the Bitcoin peer-to-peer payment system was used. Experiments have shown that taking into account the variability of the behavior strategy of the system nodes, the possibility of combining them into a group and adjusting the complexity of the block during mutual information coordination increases the probability of system stability by an average of 4% relative to other control systems.

Key words: algorithmization, blockchain, stochastic switchable environment, network parameters, variability of the behavior strategy.

1. INTRODUCTION

This article summarizes the research of a stochastic switchable environment operating in discrete time (for example a distributed ledger technology (DLT) systems built on the blockchain (BC)) and the algorithmization of their functioning. The automatic system operation model with distributed registry technology was discussed in the previous publication [1]. The development of a special mathematical system with a distributed registry was the main goal of this study. The theory of automata formed the basis of the research, methods of bidirectional interaction for correct

collaboration were used, and a mechanism for the functioning of a distributed registry system was implemented. The automaton model has been obtained and studied.

The rules for forming a block chain to achieve mutual information coordination are proposed in the second part of the study [2]. The corresponding process is described there, and a mathematical model is presented. A distinctive feature of the model is that the system is represented by with the finite automata theory.

2. ALGORITHMS OF DLT BC SYSTEM AND INDIVIDUAL NODE OPERATION

Based on the representation of the DLT BC system as a stochastic switchable environment E operating in discrete time $t \in N_0$, and the variability of the behavior strategies of the system nodes during MIC achievement, algorithms for the functioning of the DLT BC system and an individual node have been developed, Figures 1, 2.

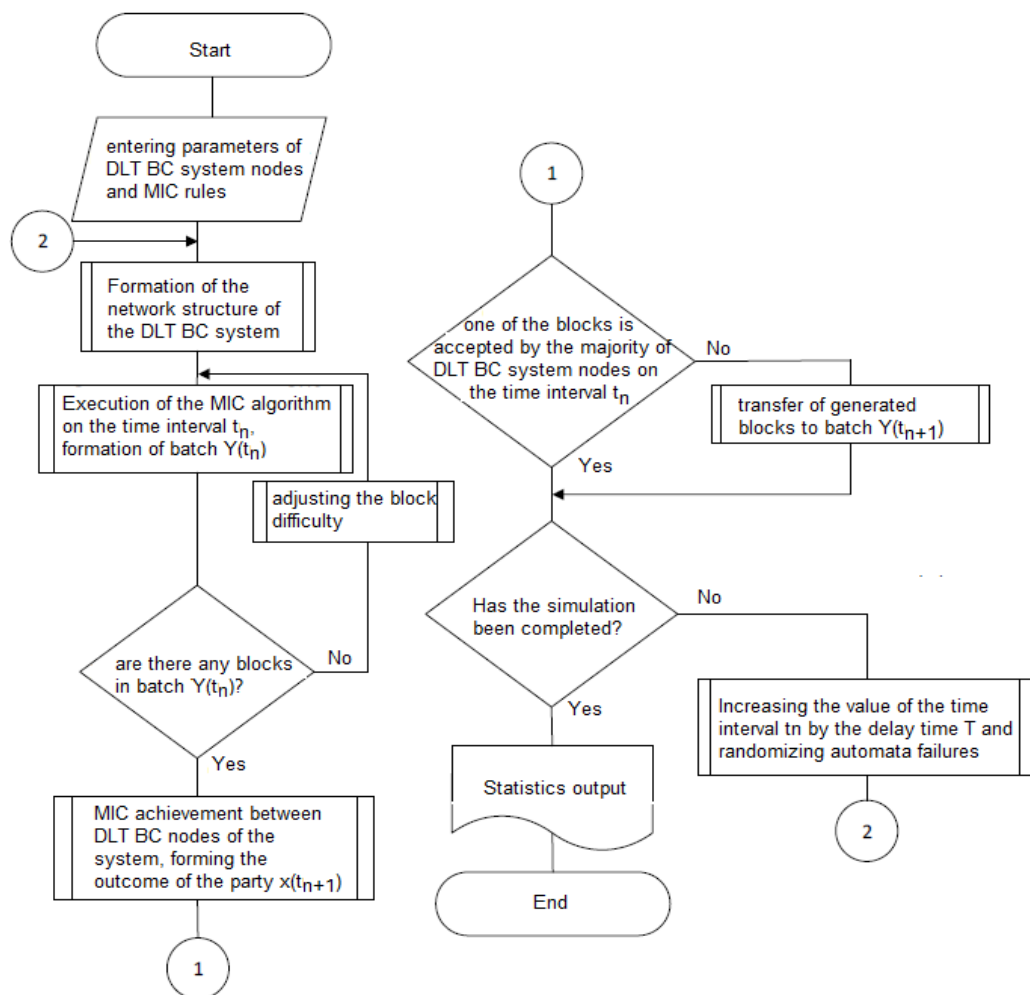


Figure 1. The algorithm of the system working

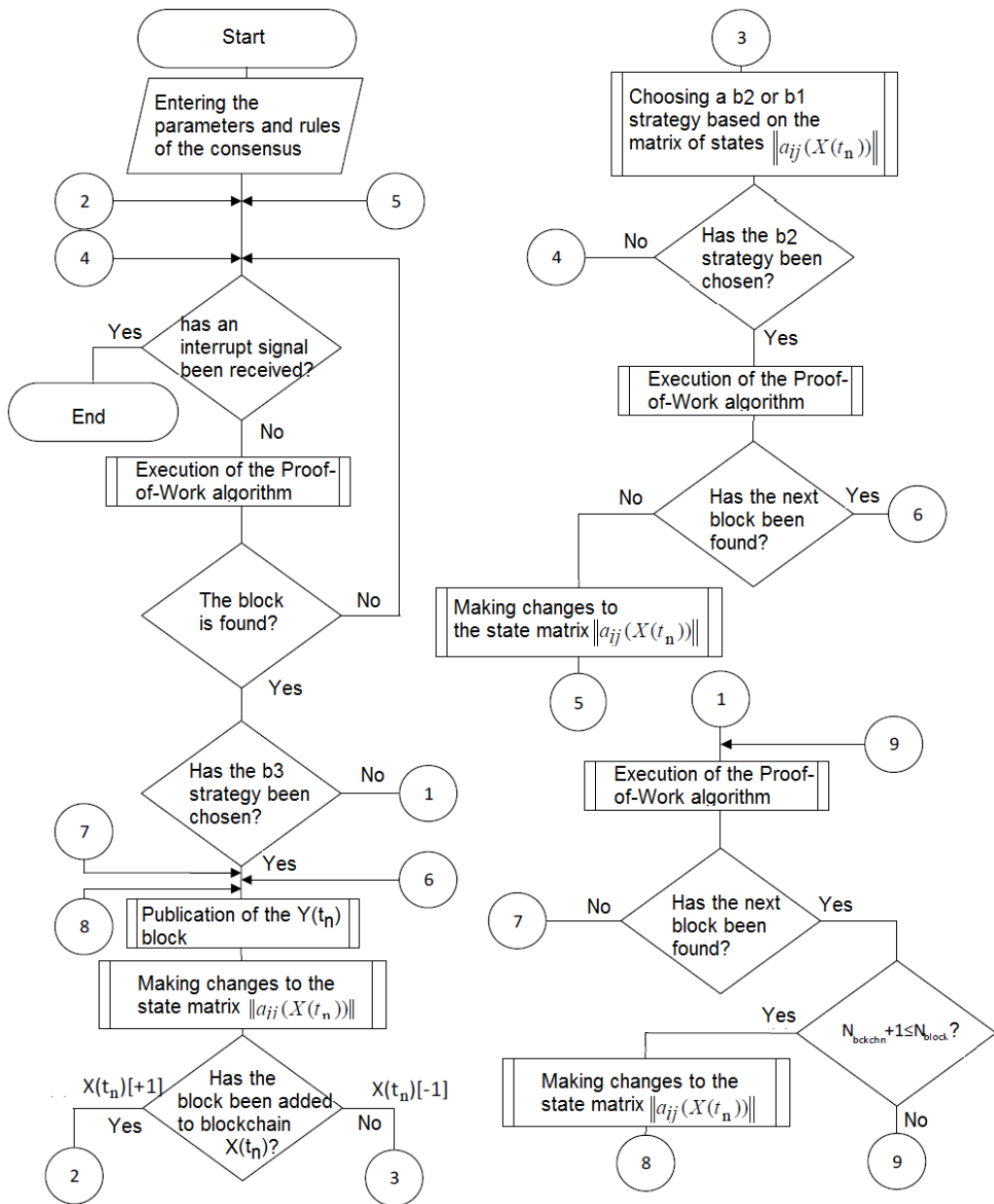


Figure 2. The algorithm of the node functioning

The algorithm of functioning of the DLT BC system is iterative and takes into account the possibility of node failures, the absence of generated blocks in the time interval t_n formed by a given delay period T of block generation.

The algorithm maintains a preset delay time T between block generation periods by adjusting the number of operations required to solve the block at each time interval t_n . Thus, the algorithm makes it possible to increase the stability of the system [3] and

meet the security requirements of specific algorithms for mutual information coordination (MIC) – the average number of block generations over the time period T .

The algorithm of the functioning of the DLT BC node of the system ensures the formation of a strategy for the behavior of the node [4]. The choice of behavioral strategy options is carried out by a system of two matrices of states $\|a_{ij}(X(t_n))\|^+$ and $\|a_{ij}(X(t_n))\|^-$: favorable $X(t_n)[+1]$ and unfavorable $X(t_n)[-1]$ reactions of the environment E , respectively. During the game Γ [1], the automata are trained and make changes to the elements of the state matrices that determine the probability of the automata's transition [5] from one state μ_j^i to another.

Thus, algorithms for the working of a separate node and DLT BC system during the achievement of MIC are presented, providing a given average delay time for block generation by changing the complexity of block generation at each time interval, depending on the choice of node behavior strategies and system centralization.

3. THE MODULAR STRUCTURE OF THE DLT SYSTEM OPERATION MANAGEMENT SOFTWARE BASED ON THE BLOCK CHAIN

When developing the software for the DLT BC management system, such statistical data on the functioning of real peer-to-peer payment systems [6] were considered as: the dynamics of changes in the number of nodes per unit of time, the probability of failures, the dependence of the number of attempts to form a fork version of BC on the centralization of the DLT system, etc. The data obtained was taken into account when forming databases of network parameters. The modular structure of the DLT BC management software is shown in Figure 3.

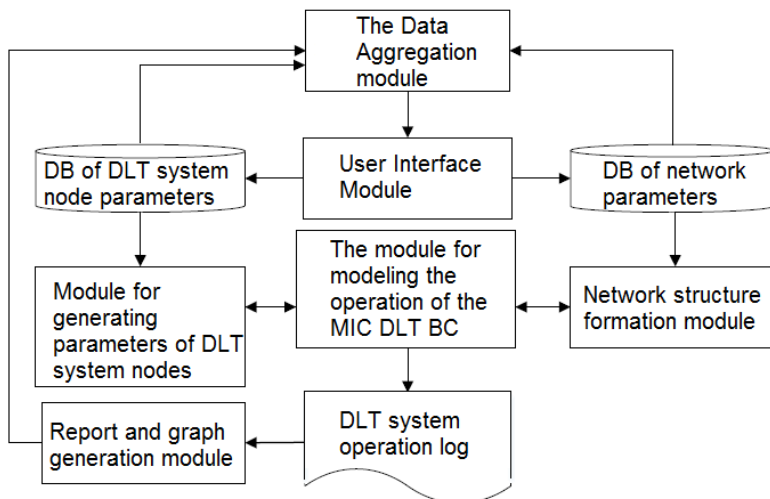


Figure 3. Modular structure of DLT BC system control software

The BC validity determination module allows you to use the implementation features of various MIC algorithms to determine the order of adding blocks to BC, as the rules of the longest BC and the heaviest BC.

The decomposition of the developed modules for generating the parameters of bidirectional interaction for correct collaboration are shown in Figures 4 and 5.

Taking into account the specifics of implementing protocols of specific DLT BC systems is implemented in the BC validity determination module (Nakamoto MIC [7], GHOST, etc.) and the network parameter database module by downloading parameters from the user interface module, Figure 5.

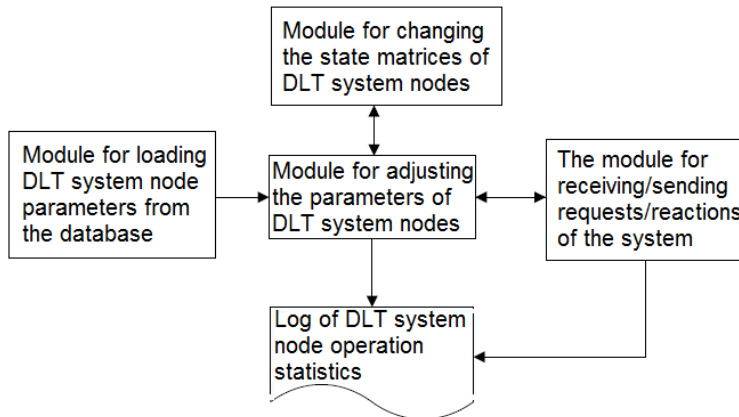


Figure 4. The structure of information interaction in the module for generating parameters of DLT BC nodes of the system

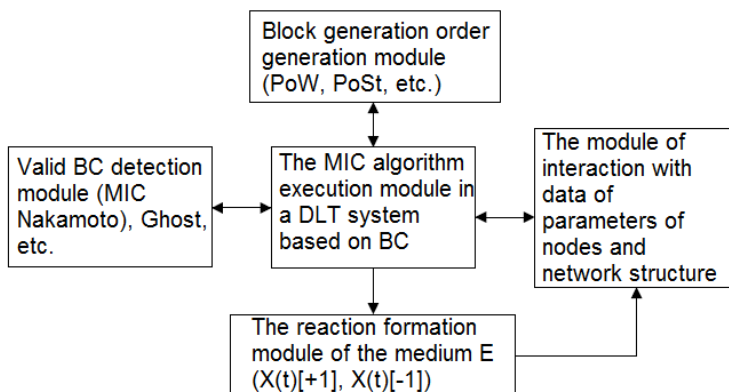


Figure 5. The structure of information interaction in the module for modeling the operation of the MIC algorithm of the DLT BC system

The structures shown in Figures 3-5 are implemented as software in the C++ Builder. The program is designed to run under the Windows operating system (Windows 7 and later), work under other operating systems is not provided.

4. THE RESULTS OF THE EXPERIMENTAL STUDY

During the experiments, the effectiveness of the developed special software was proved. To evaluate the effectiveness, data from the Bitcoin peer-to-peer payment system [8] was used. During a given period (1 billion The Nakamoto MIC algorithm

was executed between 10,000 nodes of the system. At the same time, during the first 100,000 cycles of the simulation, there was a significant deviation from the indicators of the real system due to the training period of finite automata. With frequent changes in environmental conditions (more often than once every 10,000 clock cycles), modelling also did not provide satisfactory results due to the inability of automata to choose the optimal behaviour strategy. Therefore, the use of the developed special software is advisable after training a team of finite automata on a specific implementation of the MIC algorithm and with the relative stationarity of the operating environment, i.e. low probabilities of adding and removing nodes from the system during the execution of the MIC algorithm.

During the achievement of the MIC, the nodes of the system form the value of the centralization coefficient of the system based on statistical information. In the case of generating two or more blocks within the same time period, nodes, based on statistics, select the block whose owner has a lower resource capacity value. This rule increases the stability of the system (the probability of forming a single BC) with an increase in the value of the resource capacity of the node (pool) in relation to the regular operation of the MIC algorithm, Figure 6.

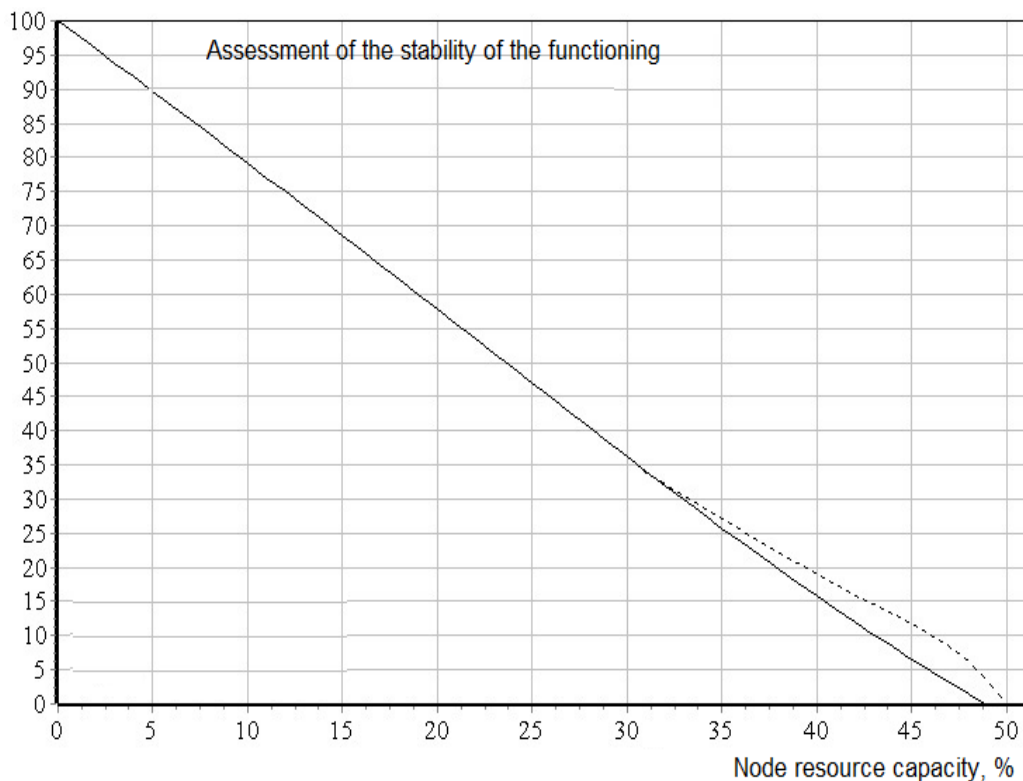


Figure 6. The dependence of the assessment of the stability of the system on the resource capacity of the node: a) — the regular operation of the MIC algorithm; b) --- the developed algorithm that takes into account the abnormal functions of nodes and the centralization of the system

Experiments have shown that taking into account the variability of the behavior strategy of the system nodes, the possibility of combining them into a group and adjusting the complexity of the block during MIC increases the probability of forming a single BC (system stability) with a resource capacity in the range from 33% to 50% by an average of 4% compared to other DLT BC control systems. not taking these factors into account.

5. CONCLUSION

The developed modular structure of the software for the management process of the DLT BC systems management system, when implemented, provides a value for assessing the stability of the system, taking into account factors that affect the likelihood of alternative block chains being formed: the implementation of abnormal functions, network centralization, and the implementation of the MIC algorithm.

1. An algorithm has been developed for the functioning of a distributed ledger system based on a block chain, which provides a set average delay time for block generation, depending on the options for node behavior strategies and the system centralization coefficient.

2. Elements of special software for managing the operation of a distributed registry system based on a block chain have been implemented, which provides a value for assessing the stability of the system, taking into account factors affecting the likelihood of alternative block chains being formed.

The results obtained can be applied in finance, the medical industry, logistics, and public administration in the development and modernization of decentralized peer-to-peer networks used for data collection, secure storage, and processing. The directions of further research may consist in the development of new approaches to the formation of matrices of states of system nodes, the analysis of the possibility of implementing Sibyl attacks using the proposed algorithms.

REFERENCES

- [1] Kravets O. Ja. et al. Automata model of a system with distributed ledger technology based on a blockchain. *International Journal on Information Technologies and Security*, vol. 17, no. 4, 2025, pp. 79-86.
- [2] Kravets O. Ja. et al. Algorithms for achieving mutual information coordination. *International Journal on Information Technologies and Security*, vol. 18, no. 1, 2026, pp. 13-20.
- [3] Gopalan A., Sankararaman A., Walid A., Vishwanath S. Stability and Scalability of Blockchain Systems. *Proceedings of the ACM on Measurement and Analysis of Computing Systems*, vol. 2, no. 4, 2020, pp. 1-35.
- [4] Li Y. et al. PCE-GNN: a node feature-enhanced graph neural network with pre-clustering strategy. *Machine Learning*, vol.114, no 8, 2025. DOI: 10.1007/s10994-025-06802-4.

- [5] Guo Y., Di C., Li S. A novel reduced parameter s-model of estimator learning automata in the switching non-stationary environment. *Neural Computing and Applications*, vol. 34, no. 6, 2022, pp. 1-14. DOI: 10.1007/s00521-021-06777-y.
- [6] Kalinić Z., Liébana-Cabanillas F., Muñoz-Leiva F., Marinković V. The moderating impact of gender on the acceptance of peer-to-peer mobile payment systems. *International Journal of Bank Marketing*, vol. 38, no. 1, 2020, pp. 138-158.
- [7] Grunspan C., Pérez-Marco R. On profitability of Nakamoto double spend. *Probability in the Engineering and Informational Sciences*, vol. 36, no. 3, 2021, pp. 1-15. DOI: 10.1017/S026996482100005X.
- [8] Li L., Wang H., Cui W. BiEnTracer: a scalable complex network-based entity aggregation and recognition system in bitcoin network, vol. 18, no. 5, 2025, art.261. DOI: 10.1007/s12083-025-02087-5.

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