THE METHOD OF CONSTRUCTING A TRANSPORT NETWORK MANAGEMENT SYSTEM

DOI 10.24411/2072-8735-2018-10055

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Keywords: *Carrier Ethernet, agents, multi-agent systems, multi-agent systems, control system, control system, transport network, TrN.*

Modern transport communication networks (TrN), along with evolving technologies of building communication networks, are in the modernization phase, consisting in transition from obsolete SDH and PDH technologies to a new generation of Carrier Ethernet (CE) carrier-class networks. At the same time, the management of communication networks working on new technologies is impossible without the modernization of the existing management system (MS). One of the ways of MS modernization is the application of the subsystem of the modeling and forecasting of the processes and the state of the TrN on the basis of the agent modeling apparatus. Formation of new modules for MS is impossible without the introduction of special monitoring and management mechanisms within the CE, which, on the whole, will create a methodological basis for the formation of monitoring and management processes for the state of TrN. The aim of the work is to increase the operational efficiency of the MS TrN to ensure the sustainability of the TrN operation. The scientific task of the work is to develop a methodology for the formation of a management system for the MS TrN, which takes into account the features of CE technology and allows to ensure the required cycle time in the large-scale network environment. The subject of the study are the developed models for the operation of the TrN based on CE technology and individual processes in the prospective MS TrN. Theoretical research methods are based on the fundamental concepts of systems theory, control theory, probability theory, the theory of constructing multiagent systems, and reliability theory. Experimental research methods include: the method of mathematical statistics, as well as the method of agent modeling.

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Для цитирования:
Логин Э.В., Муравцов А.А. Методика построения системы управления транспортной сетью связи // T-Comm: Телекоммуникации и транспорт. 2018. Том 12. №3. С. 69-74.

For citation:
Login E.V., Muravtsov A.A. (2018). The method of constructing a transport network management system. *T-Comm*, vol. 12, no.3, pp. 69-74.

Introduction

Increasing the operational efficiency of the management system (MS) at the technological and organizational and technical levels of management in order to ensure the stability of the transportation network (TrN) operation requires the construction of a methodology for the formation of an MS that takes into account the features of Carrier Ethernet (CE) technology and allows to provide the required value of the control cycle duration in a large-scale network environment.

The task related to the development of a promising MS begins with the definition of the boundaries of the control object. In the presented work, this task is solved taking into account the chosen control object, in the role of which the TrN acts. CE technology, on the basis of which TrN operates, will allow to expand the operational management capabilities for the MS TrN. The CE technology is designed to transfer Ethernet from local networks to transport networks. At the same time, unlike Ethernet in CE, a set of OAM functions (monitoring, control and management) is standardized to improve reliability. Standards [1-3] describe the functional composition of OAM. And the implementation of these functions has not been solved for today.

Types and characteristics of models in the MS TrN

The key components of the methodology are the developed models of the processes of functioning of the prospective MS TrN CE [4-7]. The models that formed the basis of the presented methodology are:

1) The discrete-event model of the process of control and management of the TrN state allows to obtain the value of the control cycle duration, on the basis of these data, to estimate the contribution of each subprocess (check for bidirectional connectivity, fault location, etc.) to the total duration, and also to assess the correspondence of the obtained values to the required one.

2) Multiagent model of TrN functioning is oriented to:

– collection, accumulation and analysis of data;

– selection and implementation of one or several processes for monitoring and managing the status of TrN (OAM) in conditions of insufficient time resources;

– the formation of solutions for reconfiguring the TrN with the detected faults as a result of the implementation of the processes and when there are discrepancies between the measured parameters and the specified requirements for the parameters of the TrN elements.

3) The agent model of the functioning of the TrN elements and managingl in the failure conditions allows solving the problems associated with determining the length of time before the loss of connectivity of the route in the network structure and the duration of the operating time for the failure of all routes simultaneously. On the basis of these data, the model also makes it possible to generate estimates of network reliability and fault tolerance.

Since the CE technology in the work is key, the developed models include the basic mechanisms for controlling and monitoring the states of network elements. And for this purpose, the problem of a well-founded choice of the basis of the modeling components of the TrN process is also solved [5, 6].

Since TrN is a large and complex communication network, the number of sets of input data and, accordingly, the number of typical malfunctions and reconfiguration options is significantly increasing, which requires the use of a special multi-agent management system (MAMS), the structural model of which is presented in [10].

In accordance with the structural model of the MAMS TrN [10], the MAMS unit operates at the levels of operational and technological control and interacts with the TrN through the technical operation system (TOS), which performs operational monitoring of the states and parameters of the TrN elements, measuring the parameters of the TrN elements, restoration and repair of TrN elements.

In describing the interaction of MAMS and TrN, the basic operations are [11]:

– registration, analysis and evaluation of technical condition of TrN $A_{REGke}, C_{Ak}, V_{ke}$;

– measurement of the parameters of the elements of TrN on the basis of the assessment of the technical state of the elements of TrN P'_{ETrCe};

– transmission, collection and processing of measured data $P_{ETrNe}, S_{AM}, y_{1 \dots 8}$;

– define the type of fault $F_{OAM}\{F_{OAMfj}\}$;

– formation of a set of decisions on the reconfiguration of the TrN S_{BBP}, V_{TrN}.

When developing the methodology for the formation of MAMS TrN, the results of the operation models of the TrN CE obtained in the AnyLogic simulation environment were taken into account [4-7].

The formalized description of the structure of the MS TrN The algorithmic structure of the methodology for the formation of the MS TrN consists of a set of logically interrelated stages in the formation of decisions on the management of TrN and is presented in Figure 1.

The first step 1 in the development of the procedure for the formation of MS in the structure of the MS TrN is to form the initial data in the form of a set of fragments $S_{TrN}=\{S_{TrN\,1} \dots S_{TrN\,k}\}$, into which the structure of TrN is broken, and the sets of elements TrN $N_{ke}=\{E_{TrN}, N_{TrN}\}$ determination of the TrN scale. Then, in step 2, the initial data is formed in the form of the structure TpC – G_{TrN}, the set of parameters of the elements TrN $P_{ETrN}=\{P_{ETrN1} \dots P_{ETrNe}\}$ and the normative values to these parameters $NP_{ETrN}=\{NP_{ETrN1} \dots NP_{ETrNe}\}$ with the possibility of further measurement of the values of these parameters and the evaluation of the TrN state.

The process in step 3 involves generating results in the form of a set of typical $F_{OAM}=\{F_{OAMfj}\}$ faults generated by OAM mechanisms, for example, inconsistencies such as loss of connectivity of the network route or loss of bidirectional connectivity of the network node, which are captured using the periodic check mechanism the integrity of the route.

Knowing the set of TrN elements and the connection between them, in step 4 a TrN structure is formed in the form of a set of fragments $S_{TrN}=\{S_{TrN1} \dots S_{TrNk}\}$, in which the classes of TrN N_{ke} elements are formed. In step 5, an OAM architecture is created in the form of CE domains $M_{TrN}=\{M_{TrN1} \dots M_{TrN7}\}$ for the ability to form control processes and control the states of the TrN elements and transmit the control information.

Further, in accordance with step 6, a number of requirements are set for the MAMS $N_{MAMS}=\{Classij, K, L, N, K_{pr}, O, T_{sm}, K_{skr}, T_{sg}, N_y, T_{mob}, T_{sob}, T_{sp}\}$ [11], which specifies the structural topological requirements and requirements on the functioning of the MS TrN with the help of parameters such as: *Classij* – the structure type of both the MS and the TrN; K – is the number of controllable elements; L – total length of the communication line; N – number of hierarchy levels; K_{pr} – the risk factor for preparing a substandard solution; O - optimality; T_{sm} – permissible duration of the control process; K_{skr} – stealth factor; T_{sg} – an admissible time of bringing the MS to the required degree of readiness; Ny – is stability; T_{mob} – mobility; T_{sob} – the allowable time of processing and transformation of information; T_{sp} – the permissible duration of the process, which corresponds to the transition of the system to a new state.

In accordance with block 7, a plurality of control units $A_k=\{A_{REGk}, A_{STATEk}, A_{STRk}\}$ is generated in each node in which A_{STRk} is the formation of a new configuration of the TrN fragment, A_{STATEk} is the state estimation of the elements of the TrN fragment, A_{REGk} is the registration and analysis of events where k Is the node number of the MAMS (fragment TrN). The component $A_{REG\ k}$ is represented as the set $A_{REGk}=\{A_{REGk1} \ldots A_{REGke}\}$, which contains e MAMS agents (TrN elements) reflecting the information space e of the elements of the k-th fragment of TpC.

At the 8th step of the methodology, in accordance with the mathematical model of the interaction process of the MAMS node and the TrN fragment, presented in [5], a lot of messages $C_{Ak}=(C_{Ak}^{in}, C_{Ak}^{out}, C_{Ak}^{OAM})$ are generated through which the control and diagnostic information is transmitted. Among the set of such messages, there are three main types: C_{Ak}^{in} – messages sent between the control units in the MAMS node, C_{Ak}^{out} – external messages transmitted between the agents of the MAMS node and the elements of the TrN fragment, C_{Ak}^{OAM} – messages for implementing the OAM mechanisms. Each type of message includes subtypes in the form of "requests", "data" and "notifications".

In 9, the algorithmic structure of the process for the operation of the MAMS TrN CE is constructed. $S_{fpMAMS} = \{G_{TrN}, A_{1\ldots8}, T_{TrN}, F_{TrN}, C_{Ak}, B_{MAMS}, T_{cm}\}$, which in [5] describes the interaction of MAMS and TrN.

At the 10th step, a database is created for the MS TpC in the form of the set $B_{MAMS} = \{D_{TrN}, M_{TrN}, A_k\}$. The information in the database can be represented in the form of a MIB-II specification for the TrN elements.

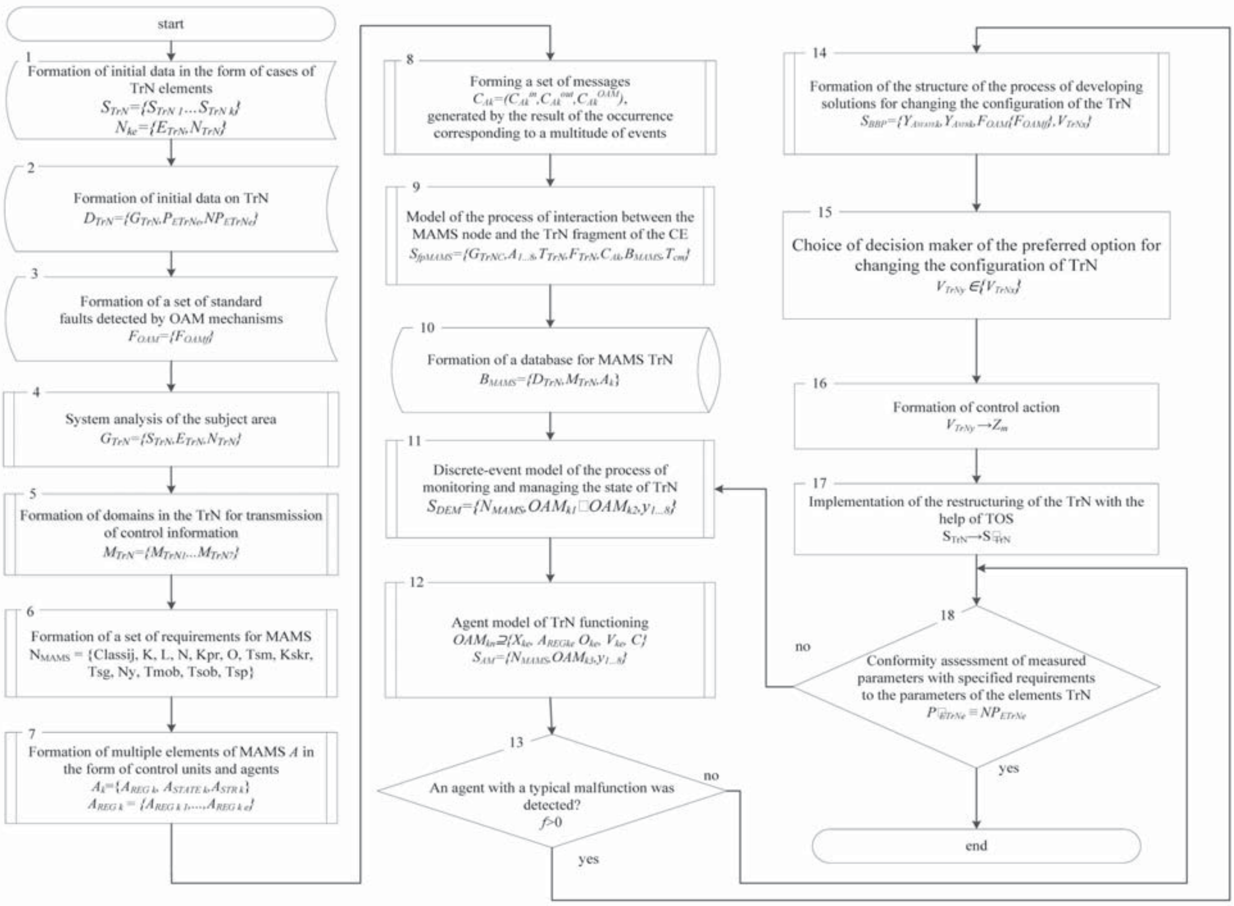

Fig. 1. Algorithmic structure of the procedure for the formation of the MS TrN CE

In blocks 11 and 12, a structure of simulation models of the process of the MAMS TrN CE operation is formed. The structure of simulation models includes two structures. In accordance with the first structure, in a step 11, a number of processes are created for monitoring and controlling TrN CE $S_{DEM}=\{N_{MAMS}, OAM_{k1} \vee OAM_{k2}, y_{1 \dots 8}\}$, where $OAM_{k1} \vee OAM_{k2}$ – processes for monitoring the status and management of TrN elements based on the fault finding result in the connectivity of the route and on the basis of the input control information from the MAMS, respectively, $y_{1 \dots 8}$ – the output data reflecting the state of the subprocesses in OAM_{k1} and OAM_{k2}. The structure of the discrete-event model of the MAMS functioning process provides a preliminary estimate of the duration of the task execution cycle for one or another OAM_{kn} process. In accordance with step 12, the structure of the agent model for the operation of the TrN CE is established $S_{AM} = \{N_{MAMS}, OAM_{k3}, y_{1 \dots 8}\}$ as a set of subprocesses in a particular process $OAM_{kn} \supseteq \{X_{ke}, A_{REGke}, O_{ke}, V_{ke}, C\}$, where X_{ke} – the input data of the process in the form of a set of parameters of the TrN elements and the requirements for them, O_{ke} – the set of operations of the current process in the form of OAM mechanisms [8,9], V_{ke} – the set of limitations and assumptions of the model, in the form of restrictions of the set of transmitted messages, C – purpose of management, according to which the current process is selected. The agent model for the operation of TrN CE was obtained on the basis of the work of the generalized OAM_{k3} process [6].

In step 13, if at least one agent with a typical F_{OAMf} fault is detected at $f > 0$, then the structure of the recovery action plan $S_{BBP}=\{Y_{ASTATEk}, Y_{ASTRk}, F_{OAM}\{F_{OAMf}\}, V_{TrNx}\}$ is formed in step 14. The structure of generating solutions for changing the configuration of the TrN includes a set of output data of the MAMS such as $Y_{ASTATEk}$ and Y_{ASTRk} – element state estimation data and data for the formation of a new configuration of the kth fragment of the TrN, and also V_{TrNx} – the formation of a set of action plans in the process of generating a plurality of S_{BBP}. In 15, the choice of the decision-maker of the preferred variant of the action plan for the reconfiguration of the TrN $V_{TrNy} \in \{V_{TrNx}\}$ is carried out. In 16, the corresponding control action of Z_m on TrN is formed, and in 17 reconfiguration of TrN by means of TOS is performed.

In accordance with step 18, the verification process for the conformity of the parameters of the TpC elements measured with the help of the TOS with the values of the parameters $P'_{ETrNe} \equiv NP_{ETrNe}$ specified in step 2 is started. If the measured values of the parameters correspond to those required, then it is considered that the task related to the control and management of the state of the TrN and its reconfiguration is completed, otherwise a different control process is selected in step 11.

Evaluation of the effectiveness of the MAMS functioning as part of the TrN

In order to perform the evaluation of the functioning of the developed methodology for the construction of the MS TrN, it is necessary to present its effectiveness when using and without MAMS. The effectiveness of the operation of the MS TrN reflects the properties of the MAMS to perform the tasks set for monitoring and managing the network conditions and the formation of solutions for changing the structure of the TrN in the context of limited computing and time resources.

The effectiveness of the operation of the MS TrN can be assessed for a number of indicators, for example, the timeliness of management and the sustainability of the TrN as a result of the work of the MAMS.

To achieve this goal, it is necessary to ensure the operational management of the TrN CE. Under the operational control we will understand the ability of MS TrN elements to perform the necessary operations within the established timeframes [12-14]. Then the measure of the promptness of obtaining control information on the management of the TrN takes into account the length of its main processes, in quality, which can take the time spent managing.

The table presents the results of a model of the process of monitoring and managing the states of the fragment of TrN from 300 nodes, obtained as a result of the program implementation of the experiment in the AnyLogic environment [15-18]. An optimistic estimate is the minimum time required for an operation to be performed (t_{min}), while the pessimistic value specifies the maximum time to perform an operation (t_{max}).

Table

Time parameters of the process functioning model in MAMS

№	Subprocess	Subprocess execution time, s		The mathematical expectation (M), s	Dispersion (D), s
		t_{min}	t_{max}		
1	Integrity check	68,6	83,3	74,48	8,64
2	Check connectivity	75,6	87,7	80,44	5,86
3	Localization	579,2	589,1	583,16	3,92
4	Diagnostics of elements	176,3	206,7	188,46	36,96
5	Development of control information	49,2	69,5	57,32	16,48

To determine the mathematical expectation and variance of the duration of the entire management process, a calculation is made in accordance with the expressions:

$$T_{ynp} = \sum_{i=1}^{n} M_j \quad (1)$$

$$D_{ynp} = \sum_{i=1}^{n} D_j \quad (2)$$

Expression (2) is calculated in accordance with the data in the table:

$$T_c = 74,48 + 80,44 + 583,16 + 188,46 + 57,3 = 983,8 \quad (3)$$

$$D_c = 2,94 + 2,42 + 1,98 + 6,08 + 4,06 = 17,5 \quad (4)$$

Based on the definition of the operability property, another important characteristic of the functioning of the control system is that the duration of the control should not exceed the permissible time, i.e. $p(T_c \le T_c^d)$.

Calculation of this indicator is made by the formula [13, 14]:

$$p(T_c \le T_c^d) = \Phi\left[\frac{T_c \le T_c^d}{\sigma}\right], \quad (5)$$

where Φ is a normal distribution function of the form $\Phi(x)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{x}e^{-\frac{t^2}{2}}dt$.

Knowing that T_c^d = 1200 c, in the course of (5) the calculated probability that the control time T_c does not exceed the allowable value is 0.6179. The obtained result indicates a high degree of efficiency of the executed processes in the MS TrN with the use of the agent modeling tool.

Conclusion

The technique for building MAMS as part of the MS TrN differs from those known by the use of a complex of original models [4-7] and scientific and technical proposals (blocks 10 and 14 in Figure 1) that allow the creation of a MS TrN CE that meets the requirements for the speedy implementation of the management cycle and allowing to minimize financial and technical resources for its implementation.

The presented technique formalizes the approach to the construction of the MS TrN with the use of mechanisms based on CE technology. The block 6 in Fig. 1 allows you to form requirements for individual subsystems of the MS, their purpose and composition. Separate blocks of the method can be used at the planning and design stages of the advanced MS.

The obtained results of the control cycle duration using MAMS, formed on the basis of Carrier Ethernet technology, were used to evaluate the efficiency of the developed methodology. The obtained result allows not only promptly (with a probability of 0.6179) to perform the management and monitoring of the state of the TrN, but also ensure the timely delivery of control information for the further formation of a set of solutions for the reconfiguration of the TrN. In general, this indicates the achievement of the stated goal of work to improve the operational efficiency of the MS TrN.

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МЕТОДИКА ПОСТРОЕНИЯ СИСТЕМЫ УПРАВЛЕНИЯ ТРАНСПОРТНОЙ СЕТЬЮ СВЯЗИ

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Аннотация

Современные транспортные сети связи (ТрС) наряду с развивающимися технологиями построения сетей связи находятся в фазе модернизации, заключающейся в переходе от устаревших технологий SDH и PDH к новому поколению сетей операторского класса на технологии Carrier Ethernet (CE). При этом управление сетями связи, работающими по новым технологиям, невозможно без модернизации существующей системы управления (СУ). Одним из путей модернизации СУ является применение подсистемы СУ моделирования и прогнозирования процессов и состояния ТрС на основе аппарата агентного моделирования. Формирование новых модулей для СУ невозможны без внедрения специальных механизмов мониторинга и управления в составе CE, что в целом позволит создать методическую основу для формирования процессов контроля и управления состоянием ТрС. Целью работы является повышение оперативности функционирования СУ ТрС для обеспечения устойчивости функционирования ТрС. Научная задача работы заключается в разработке методики формирования системы управления СУ ТрС, учитывающей особенности технологии CE и позволяющей обеспечивать требуемую длительность цикла в условиях крупного масштаба сетей. Предметом исследования являются разработанные модели функционирования ТрС на основе технологии CE и отдельных процессов в перспективной СУ ТрС. Теоретические методы исследования основаны на фундаментальных положениях теории систем, теории управления, теории вероятностей, теории построения мультагентных систем, теории надежности. Экспериментальные методы исследования включают: метод математической статистики, а также метод агентного моделирования.

Ключевые слова: *Carrier Ethernet, агенты, многоагентные системы, мультиагентные системы, методика системы управления, СУ, транспортная сеть связи, ТрС, оперативность СУ.*

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