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COMPUTER NETWORKS MONITORING AND MANAGEMENT METHODS

Introduction

High-quality service of all types of traffic is important requirement for a computer network of any scale and purpose. One of the factors of meeting this requirement is effective resource management. Currently, monitoring and managing methods of computer networks are underdeveloped. The problem of large-scale networks is particularly relevant.

Thus, it is important to improve traditional, as well as development of new methods and approaches to network monitoring and management.

Definition of the issue

Managing a large and complex distributed structure of a large corporate computer network (CN) or data center (DC) is a non-trivial task even for an experienced system administrator. Monitoring and control systems allow you automate a process and increase efficiency of the CN [1].

Such systems have existed and improved for many years, however, they are clearly equipped not enough to manage homogeneous networks.

Such systems either have insufficient functionality or require significant modifications for a specific infrastructure, or they are expensive to implement and operate, cumbersome and difficult to set up [2, 3].

In addition, the presence of standard types of control information bases such as MIB-1, MIB-2, or RMON MIB and more than a thousand of MIB's proprietary databases, with its object structure reflecting some non-standard equipment and complicating the process of implementation of monitoring systems. And the continuous release on the market of new models and even new families of models of communication equipment and the lack of unified standards for monitoring and control protocols does not allow the development of a universal monitoring system.

The optimal monitoring/control system of the CS should ensure ease of implementation, operation and modernization.

The maximum degree of automation of processes, the presence of a friendly human-machine interface, and the tolerance of the system to errors, which the network administrator could possibly make, ensure ease of maintenance of computer network [1].

An equally important fundamental requirement for a monitoring system and managing network of any scale is the ease of implementation and modernization.

Simplicity of implementation could be achieved by providing management with minimal interference into the existing network infrastructure.

Consequently, monitoring and management systems should developing based on existing and well-proven technologies and network management protocols. The obvious way out of this situation is the modular structure. Each module must solve its tasks for a particular technology and the corresponding control protocol, and be able to adapt when embedded in the system. It is significant to ensure interchangeability modules with each other.

Thus, the study of common tasks, principles and methods of monitoring modern computer networks is the task of the current interest.

Computer networks monitoring tasks

The objectives of monitoring and managing computer networks in accordance with the quality of communication standards are to ensure the quality of service of traffic QoS (Quality of Services) as a total service performance effect that determines the level of customer satisfaction with this service.

The key monitored indicators of quality of service are:

network performance or transmission speed (bit/s);

– amount of loss of packets transmitted (%);

– delay and jitter (random variances) delay (ms);

– reliability of network elements (probability of failure, average time of failure to work);

– viability of the network — the possibility of maintaining operational characteristics in case of failure of individual elements (redundancy of equipment under the schemes of cold or hot replacement).

First three parameters characterize the traffic parameters (logical level of connection), and the latter two relate to network equipment (ie, physical layer of the network), therefore, both monitoring of traffic parameters and monitoring of the state of network elements is required.

Among the network equipment parameters, it is most appropriate to monitor the availability and state of the ports, the state of the processor and the memory of the device.

Monitoring itself is not able to provide the required QoS level. To do this, they use methods and tools for managing the network, including:

– increase bandwidth network due to hardware capabilities;

– methods for reducing the load on the network (assigning traffic priorities and arranging queues, balancing the load, reserving resources, etc.).

Distributed monitoring and management of computer network

Classical distributed monitoring and control systems for the computer network are implemented in accordance with the concept of "manager-agent" [2; 3]. This architecture is distributed because there may be several managers. On managed objects, agents are installed and an object model is created. It represents all the characteristics of the object that are necessary for its control. For example, a router model typically includes characteristics such as the number of ports, their type, routing table, the number of frames, and packet protocols for channel, network, and transport levels passed through these ports. Models of network objects are used by the manager as a source of knowledge about which set of characteristics has one or another object.

The object model coincides with the logical diagram of the database (DB) of the stored object with values of its characteristics. This database is stored on the device and is constantly replenished by the results of measurements of the characteristics carried out by the agent.

The agent can perform the following functions:

– store, extract and transmit on request information about the technical and configuration parameters of the device, including the device model, number of ports, type of ports, OS type, connections with other devices, etc.;

– perform, store and transmit on request the measurements (calculations) of the characteristics of the operation of the device, such as the number of received packets, the number of dropped packets, the degree of filling the buffer, the state of the port (working or not working);

– modify the configuration parameters from commands received from the outside.

The manager does not have direct access to the database, in order to obtain the specific values of the object characteristics; he has to contact his agent over the network. Thus, the agent is an intermediary between the managed object and the manager. The manager and agent interact according to the standard protocol. This protocol allows the manager to request the values of the parameters stored in the database, and the agent - to transmit the information based on which the manager must control the object.

A manager with a certain frequency produces farrowing agents on managed devices and receives information about their current characteristics. The manager consolidates and visualizes the information received in the form of tables or graphs. In complex control systems, the CS also analyzes the information received and predicts the state for detecting the abnormal operation of the network elements. The system provides a warning about the critical state of resources, which allows you to immediately take measures to maintain the work of these resources.

The exchange of information during monitoring and control can be carried out on the same channel, in which the transmission of user traffic — in-band.

Such an approach is more economical, since it does not require the creation of a separate control data transmission infrastructure and is more reliable, since for user traffic, Level 2 and 3 protocols create backup paths when a primary failure occurs. Out-band control on a separate channel, that is, carried out outside of the user data transmission channel, also has high reliability due to the fact that the corresponding equipment can perform its functions even when some network elements fail and the main transmission channels are inaccessible. Mixed approaches are often used.

The most commonly used classical monitoring system is SNMP (Simple Network Management Protocol), which implements the concept of "manager-agent". SNMP is an application layer protocol, simplicity of which is determined by the simplicity of the Management Information Base (MIB) and the minimum requirements for the standardization of monitoring systems built on this protocol. The following items are standardized: protocol of interaction between agent and manager, MIB model description language and SNMP messages, several specific MIB models whose object names are logged in the ISO tree.

The protocol defines the format of the data, and their processing and interpretation remains at the discretion of the control stations or the network manager. SNMP messages do not have a fixed format and fixed fields.

Using the SetRequest command, the actual monitoring and management of the device takes place. The agent must "understand" the meaning of the variable that is used to control the device and, based on these values, carry out a real control action: turn off the port, assign the port of a specific VLAN line, expand the bandwidth, reserve resources, etc.

For example, the state of the network equipment can be tracked via the server agent SNMP requests: GetRequest and the agent server: Trap, specifying the desired object ID (OID) in the MIB database.

Centralized monitoring and management

Modern computer networks also use monitoring and management systems based on a centralized architecture. An example of this is software-configured networks SDN (Software Defined Networks), a technology for building communication network architectures based on the centralization of monitoring and control functions in a single point [4]. Centralization is achieved by separating network control functions (control plane) and data transmission functions (forwarding plane) in network equipment.

In traditional routers and switches, these functions are inseparable from each other, and each element makes decisions independently and relatively independently (Fig. 1).

Fig. 1. Traditional network management

In accordance with the concept of SDN [6], it is taken out to transfer the management functions to a separate device - a controller, and to the switches leave only the function of traffic transfer. The entire logic of monitoring and managing network devices in SDN is implemented programmatically, which allows developers to create their own applications for monitoring and managing the network through the program interfaces (APIs) of the controller.

In the case of an abstract representation of the network topology in SDN (Fig. 2), the administrator should only write the rule "route from A to B = packet discard" in the management software platform, and it will always work, and changes in network topology will be automatically tracked in the network operating system (Network Operating System – NOS).

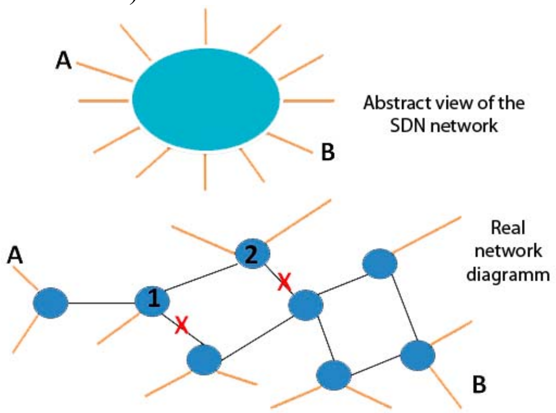

Fig. 2. SDN network management

The interaction between the controller and the switches is carried out through a protocol. NetFlow protocol is standardized for monitoring, and OpenFlow for network management.

In this case, monitoring and management are carried out at the level of flows, rather than individual packages. The rules in the switch are set up with the controller only for the first packet, then all subsequent packets of the flow use it.

The SDN architecture includes [5; 6]: SDN applications, SDN controller, control agents , whose functions are incorporated in OpenFlow switches, VlowVisor or the interface responsible for transferring control information, management and administration components (Fig. 3).

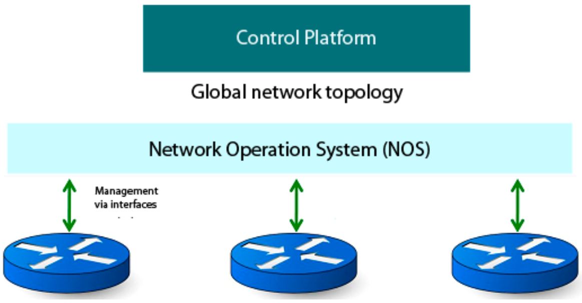

Fig. 3. SDN architecture

Applications contain requirements for the state and behavior of the network infrastructure, which are taken into account when monitoring and managing. The controller is a single centralized control point that monitors and controls the physical devices of the network through an open interface - the OpenFlow protocol. OpenFlow switches provide direct interaction between the network infrastructure and the management layer. The switchboard contains one or several redirection tables (flowtable), which contain all data about the streams of transmitted information. Records in the forwarding tables contain a set of fields with information about each packet (the number of the input and output port, the priority of the transmitted data, the counter and the types of actions that must be performed after the packet is processed (redirection, modification or reset). FlowVisor is responsible for distributing control information between data streams. By its nature, FlowVisor is a transparent proxy server between the switches and the controller. At the same time, FlowVisor determines which sets of flows belong to a particular network (switch) and, therefore, transfer control information to a specific controller. FlowVisor provides virtualization of control flow into separate network slices, each of these flows has its own control and transmission logic.

The management and administration components are static data sets that include external tasks: coordination of policies and rules established during the design of the SDN architecture, initial equipment configuration, and network resource allocation rules.

Based on the above description, SDN is a complex system of interaction of elements of both logical and physical nature, with a single intellectual point of control. The OpenFlow controller architecture consists of several levels, each of which responds to the charge of the necessary functionality. The controller acts as an element of response: it receives messages from the switches through control channels and generates responses that change the contents of the switching tables. The switch collects statistical data on the structure, state and characteristics of the data transfer level, creates labels in the redirection tables and redirects them to the controller for making further decisions.

The interaction between the control level and the data transfer level is based on two protocols: OF-CONFIG, which allows you to configure separate ones to create a high-quality control information transmission channel and the OpenFlow protocol itself, which allows you to control packet forwarding and modification.

Selection the optimal structure of the computer network monitoring and management system

The advantage of centralized monitoring and control is the ability to form a holistic view of the network status, respectively, to calculate the global optimum control and load balancing.

Among the disadvantages of a centralized approach to monitoring and network management are:

1. Low survivability of the network, because in case of failure of the central controller, the network ceases to function. When reserving controllers, there are no clear instructions on how they are communicating and deciding on the primacy/ transfer of functions.

2. It is not indicated on which communication channels the controller(s) and switches interact, according to the basic data transfer structure or parallel, and what happens when there are problems on the communication line.

3. A centralized monitoring and management system is a complex system, for the optimal management of which there is not enough information and resources. In such a system, in essence, it is necessary to solve a quadratic assignment problem (Quadratic Assignment Problem, QAP) — this is a well-known problem of discrete optimization, which is one of the most difficult tasks in this field [7].

The computational load on the central controller will be equal to K^m, where m is the number of end nodes and k is the number of switching nodes in the serviced segment. Solutions for managing such a complex system can be:

1. Decentralization (i.e., management of an autonomous network segment, which corresponds to the classical distributed approach according to the manager-agent scheme).

2. Creating a hierarchical structure. This reduces the computational load on the central node, and the degree of reduction will correspond to the ratio $Log_2 (k + m)$. However, in such a case, the global optimum control [8]. The comparative degree of conformity of the selected models is characterized by a matrix of improvement factors.

$$\mathbf{R} = \left\| r_{ij} \right\|, \ 1 \le i \le n, \quad 1 \le j \le m.$$

3. Application of heuristic or metaheuristic methods for optimizing large systems [9], in particular methods of taboo — search.

The optimization procedure is divided into several stages.

At the first stage — preliminary planning — the most common properties of the network are determined, in particular, the number and specifics of mobile services, network configuration parameters, etc.

At the second stage, an overview of the possible location of the switches is made, binding to the real network, the choice of methods for calculating transmission losses, the calculation of network resources. Based on this data and the selected transmission model, the switch parameters are planned — the size of the coverage area and the bandwidth resource. Some important parameters have a significant effect on the required channel resource, for example, the sensitivity and gain of transmitters of an SDN switch and SDN controller, cable losses and distribution medium, fading threshold, etc. Based on the geography of the network and the resource of the channel, it is possible to evaluate the various possibilities of creating a network segment using the optimization algorithm. The objective function is a combination of the achievable area of operation with a QoS of at least a given, optimal throughput with restrictions on costs. Geometric characteristics and capacity planning play a large role in network planning. When planning the geometric characteristics, the size of the network is determined, while the results of capacity planning determine the number of SDN switches used in the future and, accordingly, their capacity.

At the third stage, the adjustment and coordination of the parameters and structure of the network is made according to the results of testing each switch. According to the results of experimental studies carried out (if necessary) correction of the previous stages of the plan.

The goal of the network operator is to minimize costs (for example, by increasing the radius of the cells) so that the QoS values expressed in terms of the maximum allowed loss P_0 * and the GoS (GoS — Grade of Service) class indicators, denoted as P_b * and P_d *, meet the requirements. We formalize the objective function as follows:

$$\max_S R, \ P_0 \le P_0^*, \ P_b \le P_b^*, \ P_d \le P_d^*,$$

$S = \{RRR, CAC, R\}$ — Variety of optimization parameters

The basis of the integer combinatorial programming model used for the uplink is the classical minimization problem

$$\min\left(\sum_{j=1}^{m} c_j y_j + \mu \sum_{i=1}^{n} \sum_{j=1}^{m} u_i \frac{1}{r_{ij}} x_{ij} \right) \qquad (1)$$

subject to normalization

$$\sum_{j=1}^{m} x_{ij} = 1, \quad i \in I \qquad (2)$$

and additional restrictions

$$x_{ij} \le y_j;\, x_{ij}, y_j \in \{0;1\};\ i \in I,\ j \in M \qquad (3)$$

The first term in the objective function corresponds to the total normalized cost, where c_j is the resource consumption of the j-th switch.

Since $1/r_{ij}$ is proportional to the signal power from the i-th control point (CP) associated with the j-th switch, the second term describes the desired CP for which the total resource consumption is minimal. Since the criteria for finding a minimum for both terms are contradictory, a certain compromise coefficient is introduced. Condition (3) is a guarantee that each st CT is associated with a single switching node. Limiting condition (4) means that QDs are specified only for those points where switches are installed. Note that since the variables are binary, in each valid solution, all active connections can be assigned to only one switch.

It is proposed a sliding posteriori optimization algorithm. The concept of a balance between detailed search in the field of promising solutions and going to neighboring areas to find solutions of even better quality (lower value of the objective function) is implemented. However, such a search may require a lot of computation time. By searching in some promising area of solution space, you can miss other, perhaps even more promising areas. On the other hand, without an in-depth study of the neighborhoods of good solutions, we will only find low-quality solutions. The balance between an in-depth search in the vicinity of good solutions and the study of the entire solution space for finding other promising areas shifts in one direction or another according to the results of the previous analysis.

It can be seen that in the second case, local extremes are almost completely excluded from consideration.

In Fig. 4 shows graphs of the change in the integral component of the objective function — the total delay of routing to ensure data delivery with the required quality of service — when searching for the optimal placement of one of the switching nodes (SDN switches). Function 1 is calculated without regard to additional delay components, disconnections. Function 2 is calculated with these components in mind. The smoothness of curve 1 is due to the connection and disconnection of users in the mode of independent transmission.

Curve 2 is smoother due to the summation of the components of the transmitted signal, which are random in nature and do not depend on each other. More importantly, when these components are taken into account, the resulting required power of switching nodes decreases on average by about 4 – 5 %.

After optimizing the placement (Fig. 5), saving of the resource of switching nodes considering component packets during parallelization is more noticeable.

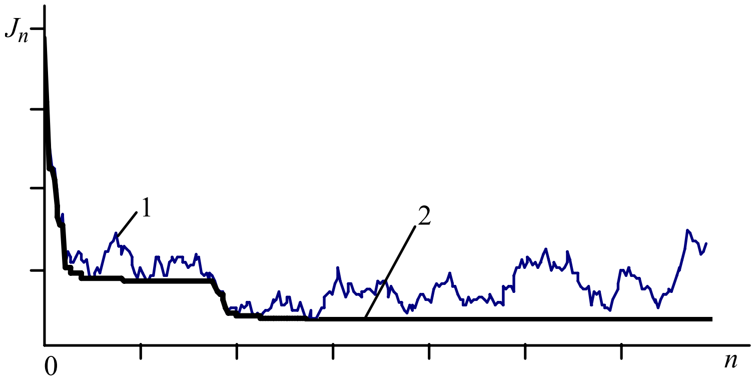

Fig. 4. Module modification of the resulting objective function in the optimization process: 1 — Classic taboo-search; 2 — Taboo-search with a sliding posteriori optimization

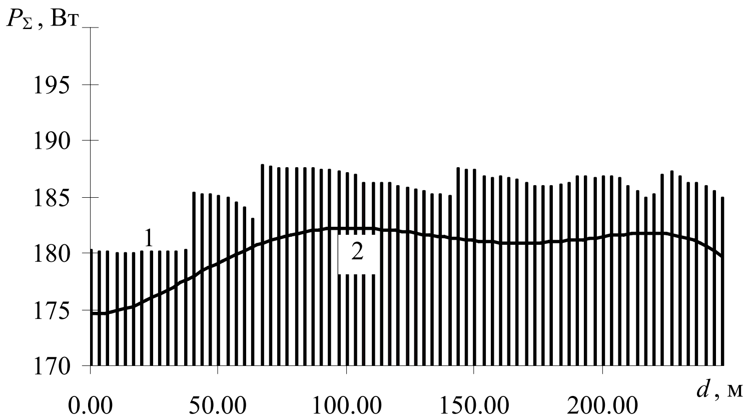

Fig. 5. Changing the parameter S_{IR} of the objective function when the switching node moves along the horizontal coordinate: 1 — Classic taboo-search; 2 — Taboo-search with a sliding posteriori optimization

Thus, upon reaching the optimal number of hierarchy levels and the optimal number of devices (final and intermediate) at the same level, there is an improvement in the quality of service in a software-configured network.

Conclusions

Modern computer networks should serve resource-intensive applications such as voice and video, CAD and cloud services that generate huge amounts of traffic with a given quality, subject to limited resources.

Classical distributed systems for monitoring and managing a computer network are implemented according to the concept “manager–agent”, use MIBs and transmit messages via the SNMP protocol. The advantage of such systems is their distribution and ease of implementation, tested for decades. The disadvantage is the control of each device separately. This introduces additional load on network resources and does not allow for efficient load balancing, since there is no coherent picture of the state. This architectural solution is suitable for office networks of small companies.

The centralized system architecture used in SDN networks allows concentrating all monitoring and management functions in a single central device — the controller. This allows you to calculate the global optimum control and load balancing. The disadvantage is the low survivability of the network, high required computing power of the central point, complexity of management due to the lack of information and resources.

A complex system management with using heuristic or metaheuristic methods for optimizing large systems is a solution to the problem. An algorithm with sliding a posteriori optimization is suggested. Upon reaching the optimal number of hierarchy levels and the optimal number of devices (final and intermediate) on the same level, there is an improvement in the quality of service.

The centralized architecture of the system allows you to concentrate all the functions of monitoring and control in a single central device — the controller. The use of the controller as a single intelligent control point allows you to significantly simplify the logic of the network, and flow control instead of packets, to reduce the load on the network. The disadvantage of this approach is the low survivability of the network, the high required computing power of the central point, and the complexity of management due to the lack of information and resources. Obviously, such architectures and solutions should be used in large corporate networks.

In conclusion, it should be noted that, in addition to the architecture, for any monitoring and management system, it is important to develop policies and rules, load balancing, i.e. development of control actions on the network. It seems appropriate to use the concept of "optimal administrator", which allows you to implement management most efficiently, regardless of the system architecture and staff qualifications.

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COMPUTER NETWORKS MONITORING AND MANAGEMENT METHODS

The distributed architecture of monitoring and management systems based on the SNMP protocol, the MIB databases and the centralized architecture based on the SDN network concept and the Openflow protocol are considered. The advantage of centralized monitoring and control is the ability to form a holistic view of the network status, respectively, to calculate the global optimum control and load balancing. The disadvantage is the low resiliency of the network, the complexity of managing a large system. Monitoring and management of such a complex system is possible with the help of decentralization, the creation of a hierarchical structure, the use of heuristic or metaheuristic methods for optimizing large systems. A method with sliding a posteriori optimization, which allows to achieve the optimal number of hierarchy levels and the optimal number of devices on the same level, is proposed.

Keywords: computer network, network monitoring, network management, SNMP protocol, SDN architecture, openflow.

Савченко А. С., Василенко В. А., Колісник О. В., Холявкіна Т. В.
МЕТОД МОНІТОРИНГУ ТА УПРАВЛІННЯ СУЧАСНИМИ КОМП'ЮТЕРНИМИ МЕРЕЖАМИ

Розглянуто розподілену архітектуру систем моніторингу та управління на основі протоколу SNMP і баз MIB та централізовану архітектуру на базі концепції мережі SDN і протоколу Openflow. Перевагою централізації моніторингу та управління є можливість сформувати цілісне уявлення про стан мережі, відповідно розрахувати глобальний оптимум управління і проводити балансування навантаження. Недоліком є низька відмовостійкість мережі, складність управління великою системою. Моніторинг та управління такою *складною системою можливе за допомогою децентралізації, створення ієрархічної структури, застосування евристичних або метаевристичних методів оптимізації великих систем. Запропоновано метод з ковзною апостеріорною оптимізацією, який дозволяє досягти оптимальної кількості рівнів ієрархії і оптимальної кількості пристроїв на одному рівні.*

Ключові слова: комп'ютерна мережа, моніторинг мережі, управління мережею, SNMP-протокол, архітектура SDN, апостеріорна оптимізація.

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МЕТОД МОНІТОРИНГА И УПРАВЛЕНИЯ СОВРЕМЕННЫМИ КОМПЬЮТЕРНЫМИ СЕТЯМИ

Рассмотрены распределенная архитектура систем мониторинга и управления на основе протокола SNMP, баз MIB и централизованная архитектура на базе концепции сети SDN и протокола Openflow. Преимуществом централизации мониторинга и управления является возможность сформировать целостное представление о состоянии сети, соответственно рассчитать глобальный оптимум управления и проводить балансировку нагрузки. Недостатком является низкая отказоустойчивость сети, сложность управления большой системой. Мониторинг и управление такой сложной системой возможно с помощью децентрализации, создания иерархической структуры, применения эвристических или метаэвристических методов оптимизации больших систем. Предложен метод со скользящей апостериорной оптимизацией, который позволяет достичь оптимального количества уровней иерархии и оптимального количества устройств на одном уровне.

Ключевые слова: компьютерная сеть, мониторинг сети, управление сетью, SNMP-протокол, архитектура SDN, апостериорная оптимизация.

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