Approach to mathematical simulation of data networking with packet routing

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Abstract. This article discusses an approach to monitoring optimization in telecommunication networks with packet routing. Mathematical model of data networking with accounting for monitoring traffic structure is described, optimization task is determined. Main attention is paid to model development on the basis of queueing theory in order to generation of reserve capacity in system. The main concept is that comparatively simple structure of monitoring network is imposed on physical structure of telecommunication network. The modeling is aimed at selection of optimum parameters of monitoring system, solution techniques for similar task are proposed. The obtained optimization task is sufficiently complicated, subsequent attempts should be aimed at searching for conditions which would enable introduction of some constraints in order to simplify its solution without noticeable loss of the model adequacy. This is especially important for asynchronous task of monitoring, it should be based on selection of the most acceptable type of objective function (linear or quadratic).

1. Introduction
While building data communication systems (DCS), at the stage of development as well as at the stage of implementation it is necessary to account for management of DCS devices of telecommunication network. In large networks such task is non-trivial and should be analyzed at designing stage. This task should be based on development and solution of mathematical model of designed network with accounting for problems of packet routing and switching, as well as accounting for packets and disturbances induced by monitoring systems, solution of monitoring optimization task and analysis of monitoring frequency for various situations.

The main concept is that comparatively simple structure of monitoring network is imposed on physical structure of telecommunication network. Monitoring system can be a subset of telecommunication network, or can be implemented on the basis of techniques differing from basic network. As a consequence, Markov network models can be accepted, then it becomes possible to obtain exact analytical description of optimization task.

In Section 2, we review the previous work in DSC monitoring. Section 3 addresses the question of useful DSC modeling features. Section 4 presents the model of data networking system.

2. Related works
Traditional heterogeneity of both telecommunication systems, computer networks, network data resources, and the range of their users complicates non-prejudicial monitoring and analysis of
telemacommunication architectures and resources. In this regard, while operating telecommunication systems and computer networks, it is required to apply sufficiently wide range of modern engineering solutions of their monitoring and analysis (for example, radio monitoring [1], simulation of telecommunication systems [2], multi-levels heterogeneous routing [3], automatic monitoring & detection system for grey traffic [4], monitoring services for scalable heterogeneous distributed systems [5]), which would improve efficiency of operation of telecommunication networks.

Analysis of such systems is usually based on Queuing System theory [6], various approaches are applied – both direct analytical description with a focus on particular targeted region [7], and more common application for Markov flow modeling of High-Reliability Telecommunications Systems [8] - for network flows analysis [9], in large-scale (military) personnel systems [10], for transport of mixed-size sediment particles under unsteady flow conditions [11], for analysis of waiting time process of Markov type [12].

The tasks, obtained as a consequence of analytical description, are solved both by conventional optimization methods ([13], [14]), and by heuristics. The range of methods is rather wide and makes it possible to achieve practical solution of nearly all optimization scenarios.

Total variety of tools used for application analysis of diagnostics of computational networks can be subdivided into several large classes.

- Management system agents supporting functions of one of conventional MIB (Management Information Bases) and transferring data over SNMP or CMIP (Common Management Information Protocol) [15]. In order to receive data from agents, manage system is usually required, which automatically collects data from agents.
- Embedded systems. These systems are made in the form of firmware modules embedded into switching equipment, as well as in the form of software modules embedded into operation systems [5]. Generally, the embedded management modules also act as SNMP agents transferring data on device state for management systems [16].
- Protocol analyzers. They are soft- or firmware systems, which, contrary to management systems, are limited only to monitoring functions and traffic analysis in networks.

The concept of this article is that comparatively simple structure of monitoring network is imposed on physical structure of telecommunication network. Monitoring system can be a subset of telecommunication network, or can be implemented on the basis of techniques differing from basic network. As a consequence, Markov network models can be accepted, it becomes possible to obtain exact accurate analytical description of optimization task.

3. Mathematical simulation of data communication system in monitoring subset

Data flow diagram of the considered system is illustrated in figure 1 (λ(0)-common flow, λ(1)-monitoring station flow, λ(2)-flow from controlled devices, Mon. = monitoring station).

![Figure 1. Data flow diagram in data communication system.](image-url)
Let us consider data networking from the point of view of its description in terms of queuing systems (QS). In this model messages sequentially pass via some nodes (switching devices). Such approach makes it possible to consider data communication system as Network of queuing systems [17], where each QS can be considered separately, but all of them are characterized by interrelations between their parameters. For illustration purposes below is given the simplest matrix of intensities of internode flows corresponding to figure 2, where only flows between nodes i-1, i, i+1 and i+2 are depicted. Intersection between column k and line l shows flow intensity corresponding to flow from node k to node l. In figure 2 the flows between nodes i and i+1 are depicted with accounting for elements of switching matrix, which characterize intensity distribution of input flows in output flows for given node:

\[
\begin{pmatrix}
0 & \lambda_{i-1,i}^{(0)} + \lambda_{i-1,i}^{(1)} + \lambda_{i-1,i}^{(2)} & 0 & 0 \\
\lambda_{i,i+1}^{(0)} & 0 & \lambda_{i+1,i}^{(0)} + \lambda_{i+1,i}^{(1)} + \lambda_{i+1,i}^{(2)} & 0 \\
0 & \lambda_{i+1,i+2}^{(0)} + \lambda_{i+1,i+2}^{(1)} + \lambda_{i+1,i+2}^{(2)} & 0 & \lambda_{i+2,i+1}^{(0)} + \lambda_{i+2,i+1}^{(1)} + \lambda_{i+2,i+1}^{(2)} \\
0 & 0 & 0 & 0
\end{pmatrix}
\]

![Figure 2. Intereation between QS parameters.](image)

While using QS theory as a model, it is required to determine for each included device what is a queue block, a service device, and what is request source. In such cases I/O exchange buffers serve as queue blocks.

Up-to-date DCS devices are equipped with sufficiently large buffers, and in combination with modern data transfer protocols this provides possibility to consider all DCS devices as having unlimited I/O buffers. Similar assumption makes it possible to use QS with unlimited queue length (the model considered below does not imply any constraints on QS type, and application of this constraint can be useful for task solution [18]).

Service devices are data transfer channels, all of them are characterized by certain throughput. Each channel can be presented by one or two independent service devices.

Request sources in DCS model are concentrators of local networks or single devices (servers, network printers, and so on) connected directly to ports of commutating switches and routers.

4. Model of data networking system

Now, let us consider a model where each channel is presented by two service devices, and network nodes preset switching matrices for interrelation between flow parameters. The values of switching matrix are taken from known intensities of request flows (packets) and their distribution at each commutating switch (router). Such description sufficiently well characterizes the process of switching...
and static routing. In practice, large networks usually operate with more complex protocols such as RIP (Routing Information Protocol), OSPF (Open Shortest Path First), EIGRP (Enhanced Interior Gateway Routing Protocol) and others, however, if the process of rerouting is not considered, and it should be infrequent, then such model can also serve as adequate description for such DCS.

More exact description is required by necessity to separate flows generated by request flows. In order to solve this task, it was proposed to detach background flow of requests and flows related with monitoring of devices (figure 3). Such separation is required for assigning of individual routes and traffic analysis generated by requests from monitoring station and responses from devices.

Input parameters for node are flow intensities $\lambda_{ij}$, where $i$ is the outgoing flow node index, $j$ is the incoming node index. Different nodes have different number of inputs/outputs, let us denote it as $m_i$, where $i$ is the node index. Another node characteristics are elements of switching matrices $\rho_{ki,l}$, where $k, l$ are input/output via which the flow passes (figure 4). Then, the intensity of flow from the $i$-th node to the $j$-th node can be presented as follows:

$$\lambda_{ij} = \sum_{k=1}^{m_i} \rho_{i,f(k,j)} \lambda_{f(k,j),i},$$

(1)

where $f(i_1,i_2)$ is the function which preset allocation of input and output indices, it was introduced just to simplify the order of their numeration. Therefore, summation over all I/O was performed.

![Figure 3](image-url) Request flow structure in simulated DCS.

![Figure 4](image-url) Schematic diagram of DCS unit and interrelations between flows.

The simulation is aimed at study of the system upon various behavior of DCS monitoring systems, which introduce additional data flow into common network traffic. Since this flow is not related with common data flows, it would be reasonable to introduce separate intensities for this flow, i.e. one more set of equations is required, which will describe distribution of monitoring system traffic. In its turn, the monitoring task is subdivided into two constituents: active monitoring by certain controlling station and data sent by DCS devices.

Using a number of expressions, we proceed from generating function $Q(z,\tau)$ to the required one:

$$P_n(\tau) = \exp \left[ -\tau \left( 1 + R(\tau) \right) \right] \left[ A_{rn}(0,\tau) + \int_0^{\tau} A_{rn}(\sigma,\tau) f_i(\sigma) d\sigma \right]$$

(2)

Knowing conventional probabilities that at the instant of time $\tau$ there are $n$ packets in channel (provided that at $\tau=0$ there were $l$ packets) (11) and distribution density of waiting time of the $(n+1)$-th packet, average waiting time of a packet in queue $L_{ij}$ for this channel and dispersion of waiting time $D_{ij}$ can readily be obtained. Therefore, determining all conventional probabilities (2), we obtain the
set of variables \( Lq_{ij} \) and \( Dq_{ij} \), which characterize loading of nodes (routers). Setting certain range of permissible variation of these variables in monitoring and solving optimization task, we can determine optimum monitoring frequency.

5. Conclusion
The considered approach to mathematical simulation of data networking with packet routing makes it possible to analyze telecommunication networks with non-stationary flows. In addition, it is also possible to study flows with various components, in this case the interest was attracted to monitoring of data networking, hence, the traffic was subdivided into three components: \( \lambda^{(0)} \) – common traffic (packet structure from various applications was of no concern), \( \lambda^{(1)} \) – monitoring system traffic, and \( \lambda^{(2)} \) – asynchronous monitoring traffic generated by devices. The simulation was aimed at selection of optimum parameters of monitoring system, solutions of such task were proposed.

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