Modeling and optimization of transmission and processing of data in an information computer network

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Abstract. The paper presents a comparative analysis of the routing algorithms that allows optimizing the process of transmission and processing of data in information computer networks. A special attention is paid to multipath methods of data transmission coupled with the number of operations necessary for their performance. In addition, the authors have raised the question of a linear programming method for the purpose of the solution of the above-mentioned problem.

1. Introduction
To create an optimal control system of information computer networks (ICN) it is necessary to model the transmission and processing of data. Computer networks can combine a large number of sub-networks with a different structure that is currently a major problem.

There are several key factors that determine the difficulty of modeling:
• Scale. The network integrates multiple computers and servers, which store and transmit data on the communication links;
• A high degree of the elements mismatching includes a variety of computer types, communication equipment, operating systems and applications;
• Information computer networks combine sub-networks by using the assigned lines, satellite, radio, telephone channels, etc.

ICN regulation should change the transmission and processing of information in the network. ICN should also ensure an optimal use of resources, as well as the compatibility of network equipment and forecasting work.

A number of challenges that require solutions in ICN operation have been revealed. These tasks include:
• providing control algorithms adaptability in situations when the available information is not sufficient for decision-making;
• forecasting ICN operation to improve management productivity;
• making decisions that correspond to real-life situations;
• providing an operation system with self-management to improve it.

Systems of data transmission often operate in the conditions of sizeable fluctuations of transmission link properties through which data are transferred. Such fluctuations depend on external conditions, as well as on changes in a mutual position of the receiver-transmitter.

When modeling such channels the model of hidden Markov process is often used. A special case of this process is Gilbert model in which the condition of a transmission link is simply described in terms
of ‘good’ – ‘bad’, and transitions between them are described by a Markov chain. By optimization of the operation of data transmission systems it is usually required to maximize the transinformation content.

Thus coordination of the data transmission rate with the current state of the transmission link gains crucial importance. One of the known developed approaches consists of an identification of transmission link characteristics and a choice of an optimum method of signal coding coordinated with the current frequency response of the transmission link.

Though this method seems to provide results very close to optimum ones, its hardware realization is rather difficult. At the same time management methods of the data transmission rate that allow coordinating it with the current state of the transmission link are already employed in operating communication systems more or less effectively.

For example, it is possible to specify the TCP/IP protocol where a burst packages rate increases under the linear law until there is a loss of a package. After that the burst rate decreases by step in the fixed proportion and then again grows under the linear law. It is necessary to emphasize that this control method is a typical implementation of a stochastic process control on incomplete data. In fact the burst rate of the packages loss is an observed process connected both with a non-observed condition of the transmission link and with the burst packages rate.

The burst packages rate is also under control of the data flow and at the same time - of indirect measurements. In recent years the management mechanisms, in which direct measurement of parameters of a packages losses traffic and the network configured so that to provide the maximum friendliness to the user, have been offered.

The models describing the TCP/IP protocol in terms of the stochastic processes operated by hidden Markov processes have been studied extensively in recent years and proved their solvency when comparing the results of modeling with practice [1].

At the same time a simple transmission of already existing technical solutions by the wireless communication lines will lead to obviously a nonoptimal solution as the level of fluctuations in the wireless communication lines and, most importantly, their temporary characteristics differ significantly from those in fixed fiber-optical carriers and wire communication lines.

On the other hand, in the stochastic theory of management in systems with hidden Markov processes there are results that allow hoping for success during their application in management problems of data transmission systems. The offered approach is based on the following prerequisites:

- the condition of the channel is described by Markov’s walk with a final set of states and known intensity of transitions;
- the data transmission rate is an operating parameter, and the intensity of packages losses is a known monotonous function from the transmission rate and the channel condition;
- the operation purpose is a choice of such law of the change of the data transmission rate under which the maximum of an average value of successfully transferred packages is attained [2].

2. Main part

The main problem in the organization of networks is distribution of data flows by the shortest paths. Ways of data transmission, which demand time minimum, or ways with the minimum hindrances belong to such kind of problem. Accordingly, path optimization has to be carried out by any technical and economic criteria, and the chosen paths have to guarantee an effective use of lines and communication vertices. Thus it is necessary to make the comparative analysis of routing algorithms which are used for development and management of information traffic today.

An adaptive routing usage allows one to reduce the average time of the package finding in a network, gives a chance to reduce costs of its delivery to the recipient by networks and to increase the general reliability of the network because of an automatic choice of a route on the basis of network topology data. But all these features hugely load computer centers of vertices. Therefore the use of adaptive routing is possible in the limited mode.
For this reason there is a problem of software development of the path choice optimization for the purpose of load reduction on computer centers, and also receiving the possibility of multipath routing use.

At a choice of the most suitable route for sending packages to the following knot we will use the directive graph. The vertices of the graph are routers, and edges connecting vertices are physical communication lines, to each of which some integral value corresponds. Such value is represented by the ‘cost’ of a package transfer on it, depending on time wasting during data transmission.

Today there are some algebraic methods, which allow describing a process of receiving results in a form convenient for the subsequent researches. For this purpose it is necessary to analyze known methods for an assessment of the applied importance and restrictions on their use.

2.1 Queueing Theory
Queueing Theory plays an important role in ICN operation modeling. In due time, a theory use has allowed a solution of many applications, for example, modeling of the backbone networks which operate the traffic between the systems.

It should be noted that this theory covers a wide range of models, among which we can mention:

- Jackson networks;
- Markov networks with different classes of requirements and parameters that depend on the state;
- Networks with a random selection of the channel in the unit and the generalized processor sharing;
- Networks of Queuing Systems requirements of different classes with the absolute priority of incoming claims and priority;
- Networks with service discipline ‘generalized processor sharing’ and different classes of requirements;
- Queuing networks with a variety of channels.

A lot of ‘queues’ and ‘service channels’, which receive service demands, are a subject of domain theory of queuing systems (QS). This mathematical algorithm is distributed in the application process for ICN analysis. Predecessors in their works substantiated and derived the general laws of the timing delay request, queue length, etc., which depend on the QS type.

On the QS basis the formation of new data transmission technologies as well as the emergence of global networks, which in their turn are associated with the information growth and computer security, has led to the need of creating and developing new ICN models [3].

Existing methods generally use the first two moments (mean and variance) of time distribution in the input stream and the service time. But they are quite uncertain, and it is not always possible to obtain reliable results. Therefore, some authors suggest the use of new approaches.

The method of Queueing Theory allows one to determine the sizes of the shortest paths between all vertices as well as the lengths of all possible paths between each set of two vertices of a network. It enables finding the smallest distances in this network.

2.2 A method of linear programming
To cut it short, these methods are connected with determination of the best program of administrative actions in a case when linear dependence, in which unknowns are in the first degree, acts as an objective function and limitations.

The problem definition of linear programming has an extreme character. It consists of determination of such variable values under which the objective function attains its maximum or a minimum depending on the problem character.

3. Graph algorithms
A special place in mathematical support of traffic choice procedures of information flows transmission is taken by the Dijkstra algorithm, which is based on the optimality principle.
3.1 Dijkstra algorithm

This method allows finding the shortest path between one node in a graph to all others. The algorithm works only for graphs without edges of negative weight though now there are generalized methods for elimination of this shortcoming (Dijkstra’s method with potentials). The essence of the Dijkstra algorithm consists in step-by-step building of the shortest routes tree from the initial vertex. At the same time it is necessary after addition at each stage of the communication line and a knot the newly formed shortest path was minimal possible on all terminal vertices which are not yet in the tree. There are calculated scales vectors of paths and there are corrected initial vectors of the shortest paths in the process of creation the shortest paths tree. The complexity of the Dijkstra algorithm depends on a way of finding vertex \( v \), and also on a way of storage of a set of unvisited vertices and a way of tags updating. In graph \( G \), \( n \) and \( m \) are respectively the quantity of vertices and the edges for searching the vertex using the shortest path to vertex \( v \) is looked through the whole set of \( n \).

The operating time of the minimization algorithm is \( O(n^2 + m) \). For the discharged graphs (for which \( m << n \)) when using special algorithms of optimization of the operation speed the operating time can amount to \( O(n \log n + m \log n) \) or even \( O(n \log n + m) \). Dijkstra method is widely applied in network programming and technologies, for example, it is used in the OSPF protocol (Open Shortest Path First) for elimination of the close paths. The using of the modified Dijkstra algorithm as an effective tool for distribution of input information flows in the main IP networks with the OSPF protocol allows one to improve the network robustness protecting against data overloads. Thus it is possible to use the residual capacity of the link as a criterion of information flows distribution. It is necessary to refer the relative simplicity of practical realization of the method to protocol merits.

3.2 Johnson’s algorithm

This method allows finding the shortest ways between all pairs of vertices in a sparse, edge weighted, directed graph. This method operates if the graph contains edges with a positive or negative weight, but there is no cycles with negative weight. Edges are stored in the form of lists of adjacent vertices. If in the Dijkstra algorithm a nondecreasing queue with priorities is realized in the form of Fibonacci heaps, the operating time of Johnson’s algorithm is \( O(n^2 \log n + mn) \).

3.3 Theory of graphs and network analysis

Graph theory is used in parallel with fuzzy-set theory and probability theory. This compatibility does not allow bringing a large class of tasks to linear programming.

At the present time, graph theory is one of the basic mathematical algorithms, which are used to study ICN behavior at the network level. One of the solutions to the problem of optimized routing and decreasing a flow of traffic in each node of the network is to use graph theory and Petri nets.

A classic Jackson network is studied under the assumption that the duration of a service application has an exponential distribution. The law of the service application time distribution is different from the demonstrated one. There is an urgent problem of analytical apparatus development for the queuing networks study with arbitrary distribution functions of service time, which attracts more and more researchers [4].

There is a method to calculate the stochastic systems characteristics of applications processing based on diffusion models. The functioning process of the application processing node is regarded as a two-dimensional diffusion process, which consists of two streams: a stream of applications receipt \((i = 1)\) and the exit stream \((i = 2)\).

\[
\frac{\partial p(x,t)}{\partial t} = \sum_{i=1}^{\infty} \left( a_i \frac{\partial^2 p(x,t)}{\partial x^2} - b_i \frac{\partial p(x,t)}{\partial x} \right),
\]

where \( p(x, t) \) – probability density admission \((i = 1)\), processing \((i = 2)\) requests: \( a \) – a diffusion coefficient, \( b \) – a drift coefficient. Moreover,
\[ a = \frac{1}{\tau}, b = D \frac{1}{\tau}, \]

where \( \tau \) – average time between the applications receipts (application processing), \( D \) – time dispersion between applications receipts (and / or processing of applications).

This approach allows using the number of new algorithms of the stochastic processing applications system.

But the network structure in this case is set apart and the model operates during the average time of receipt and applications maintenance, at the time of arrival variances, at maintenance downtime of applications and a node. Thus, this model is inconvenient [5].

If the dynamics of the applications processing was not analyzed, then it is necessary to compute the stationary distribution of working / non-working hosts of Jackson with the changing number of sites, both for open and for closed networks where nodes may fail or recover.

It has been proved that if a discrete Markov process describing the Jackson network operation with a variable structure is ergodic, its limiting distribution \( P(n) \) satisfies the following equation:

\[
P(n) = \frac{\prod_{i=1}^{m} \frac{\hat{\lambda}_i}{\mu_i}}{\prod_{i=1}^{m} \frac{\mu_i}{\mu_i - \hat{\lambda}_i}}^n
\]

where \( \hat{\lambda} \) and \( \mu \), – the intensities of the input and output stream of applications of the \( i \) – type, respectively; \( n \) – the number of working units, \( m \) – the limit number of different types applications.

4. Results and discussion

1. For the networks with the information traffic operation it is preferably to use Johnson’s method as it provides a speed gain in case of the network topology that is described by the big graph.

2. Among one path algorithms of the distance-finding it is possible to note Dijkstra’s (OSFP protocol) algorithm. This algorithm is actively used as a part of the OSFP protocol for routing in autonomous systems (the protocol of an internal lock).

3. The matrix algorithm, as well as the other multipath algorithms, has the advantage of one path, consisting in advance calculated alternative distances that eventually leads to a reliability increase of a network and a possibility of redistribution of loading between communication links.

4. A determination of the shortest path can be carried out by the methods of linear programming that allows one to estimate a temporary network lag effect under minimization of the average time of the message transmission.

5. Conclusion

Optimization of data transmission in information computer networks is connected with difficulties caused by the following factors:

- the necessity of continuous study of new technologies in data transmission, their features and features of the equipment supporting these technologies;

- strict cost and duration requirements of implementation of networks projects, as well as the users’ needs quick change in time that results in the necessity of the organization of teamwork on projects;

- the interactivity of the process of data transmission networks creation connected with continuous emergence of new services, an increase in the clients number of networks and a demand for expansion of the existing users.

Optimized transfer and processing of data in ICN will significantly reduce its work time, as well as the cost of development and support of software products.

The most important thing in the optimization of ICN is a number of information tools that ensure a constant level of reliability.
A reduction of costs on improving server software is accounted for information resources integration into a data processing center (or a few DPCs). In addition, costs for services and data communications are significantly reduced.

Therefore, the optimization of data transmission networks has resulted in the caching and compression of the data transmitted, traffic optimization, a change of transport protocol TSP, which increase the interactivity of the network application performance and reduce the volume of data transmitted.

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