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- Adaptive Traffic Management of Information Flows in Telecommunications Networks

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ABSRACT: Dynamic (non-stationary) models of global telecommunication systems with variable structure and their generalizations are considered. Optimization algorithms of dynamic, adaptive and neural network routing and principles of multi-agent processing of information flows in integrated infotelecommunication networks are studied.

KEYWORDS: adaptive traffic management, info telecommunication networks, adaptive routing, multi-agent, IP protocols, communication channels, network and neural network agents.

I.INTRODUCTION

The development of information and telecommunications systems at the present stage requires the development of theoretical foundations for the design of integrated information and telecommunications networks (ITCN) of a new generation, including telecommunications systems (TCS) and computer networks (CN), which accumulate distributed information and computing resources. Such ITCN provide their users as external agents with high-quality mass remote access services and efficient use of distributed information and computing resources using IP protocols and other means of managed communication and information transfer.

II. RELATED WORK

Improvement of ITCN is primarily associated with the development of the methodology for automation, adaptation and intellectualization of network management systems for information flows based on dynamic (non-stationary) models of TCS as complex control objects with a variable structure, methods for optimizing information flow routing processes, and principles of adaptive and intelligent traffic management using multi-agent technologies and new-generation protocols (IPv6, etc.). actual state or changes in the structure (topology) and parameters (weights of communication channels) TCS in real time, and adaptation to various uncertainty factors based on monitoring and functional diagnostics of ITCN.

III. LITERATURE SURVEY

The article discusses dynamic models of global TCS with variable structure and their generalizations, optimization algorithms and tools for dynamic, adaptive and neural network routing, and methods for multi-agent processing of information flows arising in ITCN.

The architecture of telecommunications systems and the role of network management of information flows. Globalization and other modern trends in the development of TCS as a means of controlled transmission of information flows and remote access of external user agents to the CN have led not only to a significant revision of the basic telecommunications concepts, but also to significant technological shifts.

The explosive growth of real-time traffic and its multimedia nature often generate network conflicts and congestion, blocking the normal operation of the TCS and remote access to information and computing resources distributed in the CN. The rapid development of new types of services (distance learning, e-commerce, etc.) has dramatically increased the requirements for the quality of user service and information security. These problems have led to the need to create new mathematical and simulation models of TCS as complex dynamic control objects, algorithms and protocols for routing data flows, principles of multi-agent information processing, and methods of adaptive network management with automatic resolution or prevention of network conflicts.

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IV. METHODOLOGY

The global TCS architecture proposed in [1] consists of four main (basic) subsystems:
- distributed communication system (DCS);
- network management system (NMS);
- distributed information system (DIS);
- distributed transport system (DTS).

These subsystems are interconnected and are designed for controlled transfer of information and computing resources distributed in the CN to external agents-users of the TCS at their request. NMSs play a central role in the human-machine interface and efficient organization and transmission of information flows.

New generation NMSs should be adaptive and intelligent [1-7], i.e. they should have the ability to:
- adaptation (automatic self-tuning) in relation to the changing number of users, their requests "by interests" and personal requirements for the quality of services provided, to the changing structure (topology) TCS and parameters (weights) of nodes and communication channels, etc.;
- training and self-learning of new functions and rules of operation of ITCN;
- self-organization of the NMS structure and functions depending on changes in ITCN;
- predicting and preventing failures and network conflicts.

A. Optimization and adaptation in traffic management and routing of information flows.

The task of traffic management in global TCS is divided into two interrelated tasks [1-5]:
- planning, optimization and adaptation of data flow transmission routes between TCS nodes over available communication channels;
- control the transmission of data streams along specified routes with adaptation to changing traffic, possible congestion, or changes in the topology or parameters of the TCS.

The traditional static formulation of the problem of planning and optimizing data transmission routes is based on the assumption that the structure (number of nodes, topology) and parameters (cost of communication channels) of TCS are known and unchanged. In this case, the role of an external TCS user agent is usually played by a single client that forms a request to one of the network's node computers.

The dynamic formulation of the problem assumes that the structure or parameters of the TCS may change over time, but remain known. In this case, the network information about the TCS is updated, which automatically changes (recalculates) the optimal routes for transmitting data streams.

In an adaptive problem statement, routing is performed under conditions of uncertainty, when the topology and parameters of TCS communication channels, as well as traffic and the number of users can change unpredictably. However, the available information about TCS is usually local in nature. Monitoring and updating network information via feedback channels allows adaptive adjustment of routes and algorithms for managing data flows [1-5].

B. Non-Stationary graph model of telecommunication system and its generalization.

A dynamic (non-stationary) TCS model with a variable structure and changing parameters is described by the graph [1]:

$$G(t) = G(A(t), R(t), W(t)), t \in [t_0, t_T], \qquad (1)$$

where A-nodes, R-communication channels, W-weights (parameters) of TCS communication channels, which can change over time at a given interval $[t_0, t_T]$. The use of such "dynamic" graphs and their corresponding TCS matrix models is due to the fact that the real dynamics of TCS with variable structure and changing parameters is still poorly studied.

Usually a nonstationary graph model TCS is considered as fixed:

$$G(t_k) = G(A(t_k), R(t_k), W(t_k)), t \in [t_k, t_{k+1}], k = 0,1,2,..., \qquad (2)$$

does not change its structure (link topology) and parameters (scalar weights of communication channels) at known or unknown (unpredictably changing) time intervals. In this case, the weight of the communication channel between the i-th and j-th node is set as a scalar parameter (for example, the bandwidth of the communication channel).

However, in practice, communication channels can be heterogeneous and have different physical nature. Therefore, they are generally characterized not by one, but by different parameters, i.e., a vector of parameters. For example, a fiber-optic cable communication channel is characterized not only by its high bandwidth, but also by the cost and

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length of the cable, the cost of laying it, etc. Satellite communication channels and radio channels are also characterized by a vector of specific parameters (weights).
Global TCS nodes actually correspond to various technical elements: computers, servers, hubs, etc. Therefore, failure or the appearance of new nodes will have a different impact on the functioning of the TCS as a whole. For efficient routing and data flow management, it is important for the i-th TCS node to match its weight V or the corresponding parameter vector.
Taking into account the changing weights of nodes and communication channels of the global TCS, which are generally vector parameters, is possible in the framework of the following generalized dynamic ("vector") graph model of TCS

$$G(t) = G(A(t), V(t) R(t), W(t)), t \in [t_0, t_T], \quad (3)$$

or sequences of corresponding fixed "vector" type graph models at pre-known or unknown time intervals $t \in [t_k, t_{k+1}], k = 0,1,2,\ldots$.
The need for dynamic and adaptive routing of data flows in global TCS occurs in the following cases:
- changing the weights of nodes or the cost of TCS communication channels (for example, when replacing them);
- failure (failure) in the TCS of one or more communication channels;
- adding new communication channels to TCS;
- failure (failure) of one or more TCS nodes;
- adding new nodes to TCS;
- overload of TCS communication channels;
- overload (overflow) of buffers of TCS nodes.

Multi-agent processing of information flows requires the development of dynamic and adaptive routing methods in the context of multicast and possibly multi-threaded information flows of collective use of TCS, when the number of external agents-clients of TCS, as well as the number and nature of their requests may change unpredictably over time. In this case, network congestion and conflicts may occur, which require special tools and algorithms to compensate or prevent [3-7].

C. **Criteria for routing information flows.**

Let TCS be defined by its graph model, i.e. by the digraph G (A, R, W). We call it a simple routing table τ_i nodes $a_i \in A$ the display of many nodes *A* TCS on the set of neighboring nodes $A_i \in A$ node a_i,etc.

$$\tau_i : A \to A_i. \quad (4)$$

Every node TCS $a_i \in A$ let's link the local database (DB) and the local knowledge base (KB) of routing. DB defined as the display result τ_i, etc a set of node pairs from $A \times \tau_i(A_i)$, KB — as the display itself τ_i. This allows you to take into KB account additional characteristics of the TCS, such as the network topology, the cost of communication channels, and so on.
Let each TCS node have a DB associated with it-a simple routing table. Let's call the set of such tables a simple TCS routing map. Formally, the global TCS routing map can be represented as a set of local DB.

$$T = \{\tau_i\}_{i=1}^{N} \quad (5)$$

The T routing map can be implemented as a distributed TCS DB node, which is a collection of simple routing tables. This map does not provide preliminary (a priori) routing from one TCS node to another, but only defines "neighbors" for each TCS node.
Network management of routing is performed as follows: the data receiving node f is fixed and a sequence of TCS nodes is constructed for it from the source node s by means of sequential mappings, which determine the route for transmitting information flows of the form:

$$s = a_0, a_1, a_2, \ldots, a_k = f. \quad (6)$$

At the same time, for any route (6), the ratio is valid:

$$\tau_{i-1}(f) = a_i. \quad (7)$$

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We will call the TCS routing map and its corresponding DB correct if it can be used for routing data between any two nodes of the graph G (A,R,W) .
The criterion that allows you to use the routing map to route data packets between any two TCS nodes is called the TCS communication (routability) criterion.
Based on the global DB implementing the TCS routing map, this criterion can be formulated as the following theorem.
Theorem. The TCS routing map is correct if and only if for any node $f \in A$ and for any partition of a set A into non-empty sets A_1 and A_2, such that $f \in A_2$, find node $a \in A_1$ and $a \in A_2$, for which the relation is valid (7).
From this theorem it follows that for any source node s and any useprecache data f from set A of nodes in the TCS there is a route of transmission of the data packets ie the sequence of nodes of the form (6), such that for all, is true the relation (7). Other routing criteria TCS formulated in [8].

V. EXPERIMENTAL RESULTS

D. Adaptive routing methods and principles of multi-agent processing of information flows. As noted in the 6th edition of the monograph [10], "adaptive routing is a problem that is very difficult to solve properly. Proof of this is the fact that the largest packet-switched networks (such as ARPANET and its "successors", TYMNET and the IBM and DEC network architectures) have repeatedly undergone significant changes in routing principles."
Adaptive routing of data flows has a number of advantages over non-adaptive (static or dynamic) routing, namely:
- ensures the performance and reliability of the NMS in case of unpredictable changes in the structure or parameters of the TCS;
- leads to more uniform loading of TCS nodes and communication channels by" leveling " the load or adapting to network congestion;
- simplifies data flow management in case of network congestion or network conflicts;
- increases uptime for unpredictable changes in TCS parameters and structure.

Adaptive routing is based on transmitting local information (in the form of local feedback) from neighboring nodes or global information (in the form of global feedback) from all TCS nodes. The latest information contains data about failures or delays in nodes or communication channels TCS etc.
Adaptive routing and data flow management models in global TCS can be divided into three classes [1,3]:
- centralized (hierarchical) routing;
- decentralized (distributed) routing;
- multi-agent (hybrid) routing.

The principle of centralized routing is that each TCS node transmits information about its state to the Central node of the router, which calculates the optimal route.
The principle of decentralized routing is based on the exchange of local information between TCS nodes to calculate the locally optimal route.
Multi-agent routing is a kind of hybrid (compromise) between centralized and decentralized routing. It is based on multi-address or multi-stream routing, adaptation to uncertainty factors, and analysis of possible network conflicts in order to prevent or resolve them in the process of controlled transmission of data flows over a set of optimal or locally optimal routes. Models and methods of multi-agent routing in global TCS are described in [3-5, 8].
F. Network and neural network agents in global telecommunications systems. The main functions of information processing, self-organization and management of information flows at the request of external agents - users of the global TCS are distributed among internal agents, whose role is performed by network or neural network agents.
The architecture of these internal network agents is similar to that of TCS. This shows the fractality of network and neural network agents in relation to TCS and its subnets as Autonomous systems [5,7].
Each internal network or neural network agent has its own local DB and local DB, as well as means of communication with other agents for exchanging information in the process of joint decision-making, self-organization by "interests" and automatic formation of RTS network management, which provides targeted delivery of information and computing resources at the request of external agents-users of the global TCS.
Network agents can independently make local decisions and enforce them. Therefore, they can solve emerging problems both independently and collectively.
Neural network agents are designed primarily for parallel transmission and processing of complex multimedia signals and images (2D or 3D images, etc.). as a result of training on a set of precedents from the training DB, the architecture

(topology of network neurons) and parameters (synaptic weights) of neural agents are configured for the task to be solved [1-4].
Recently, neural network agent models have been developed for adaptive routing (agents-routers) and automatic classification of web sites in natural (russian) language (agents-classifiers). Software implementation and simulation of these agents indicates their effectiveness and advantages over traditional tools [9].
For managed address transmission and navigation of data flows, network conflict resolution, functional diagnostics and state recognition of a new generation of global TCS, it is advisable to use special agents-coordinators [1-6]. The peculiarity of these coordinating agents is that their DB and KB are formed on the basis of local DB and KB agents of a lower level. Therefore, they are global in nature and allow you to assess the network situation "as a whole".
J. Multithreaded routing and fault tolerance of information flow management. The main disadvantages of single-stream routing in TCS are the following features [1,10]:
- failure or failure of at least one node or communication channel of the TCS, through which the optimal route for transmitting data flows passes, requires time-consuming re-planning (recalculation) of the optimal route (or part of it), taking into account the faulty nodes or communication channels;
- a planned route between any given source node and destination node of the TCS can cause network congestion at a time when other (for example, neighboring) nodes and communication channels may be free or underloaded.
To overcome these difficulties, it is advisable to use multithreaded routing. At the same time, not one (for example, optimal) route for transmitting data packets of the form (6), (7) $K \geq 2$ is planned simultaneously, but such routes. The higher the number K, the greater the probability of guaranteed delivery of data packets from the source node to the destination node. This increases the reliability and fault tolerance of the global TCS [1, 8].
With centralized multithreaded routing, $K \geq 2$ optimal or suboptimal routes are planned a priori based on available (fixed) or updated (dynamic) TCS status information.
With decentralized routing, each subsequent route node, starting from the source node, $K \geq 2$ plans optimal or suboptimal routes for transmitting data flows to the destination node. This method of a posteriori planning of K routes "from the reached node" requires a special mechanism for preventing loops (closed routes) [8].
The main advantage of the a posteriori K-stream routing method is that it provides automatic "bypass" of failed nodes or TCS communication channels. This allows you to quickly update information about the current state of the TCS and make the necessary adaptive corrections to the routing tables and maps [3,7,8].

VI.CONCLUSION AND FUTURE WORK

The proposed mathematical models and optimization methods for dynamic, adaptive, neural network and multi-agent (multicast and multi-stream) routing of information flows for new-generation global ITCN are an important step towards creating a theory of adaptive multi-agent (mass) service of global information and telecommunications networks [1]. This should replace the traditional statistical theory of queuing. The results obtained can be useful for creating a new generation of scientific and educational IP networks or for organizing adaptive multi-agent (mass) maintenance of GRID - infrastructures of various scales and purposes.

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