ADAPTIVE ROUTING AND MULTI-AGENT CONTROL FOR INFORMATION FLOWS IN IP-NETWORKS

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Abstract: The principles of adaptive routing and multi-agent control for information flows in IP-networks.

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ACM Classification Keywords: I.2.11 Distributed Artificial Intelligence: Multiagent systems; F.1.1 Models of Computation: Neural networks

Introduction

Evolution of informational and telecommunication system requires on the modern stage a development of theoretical bases of design for integrated infotelecommunication computer networks of new generation, including telecommunication systems (TCS) and distributed information and computer resources (local and regional computer networks, data stores, GRID-systems etc.). At this global TCS play role of tools for providing for users as external agents (clients) quality of service (QoS) for their plural access to information and computing resources, distributed in all over the world.

Improvement of global TCS is connected firstly with further development of theoretical bases and realization of methods of automation, optimization and intellectualization of systems for network control of information flow. Reason of it is that today network control network of global TCS depends significantly on network administrators and operators. However, their possibilities and abilities are limited principally.

Alternative way for improvement of network flows control in global TCS is its automation on the base of dynamical models of TCS as complex network plants of control, methods of optimization of processes of routing of data flows and principles of adaptive and intelligent control for traffic with use of multi-agent technologies and protocols of new generation (for example, IPv6-protocols). On this new way there is a possibility of consideration either only real dynamics of TCS, i.e. real change of structure (topology) and parameters (weights of communication channels) of TCS in a real time or adaptation to different factors of uncertainty on the base of monitoring and functional diagnosis of TCS.

In the paper dynamical models of global TCS with changing structure, mathematical models, optimization algorithms and protocols of dynamical, adaptive, neural and multi-agent routing of data flows are described. These models, methods and protocols of new generation are important part of modern theory of adaptive and intelligent control for information flows in global TCS. They reflects experience and scientific reserve, obtained in a process of fulfillment in 2002-2004 a state contract №37.029.0027 with the title “Adaptive methods for control of data flows in telecommunication systems of new generation” of Russian Federal Agency on Science and Innovations in the framework of Federal Scientific Technical Program “Researches and development on priority directions for science and technical development”.

1. Evolution of TCS and Intellectualization of Network Control

Globalization and other modern tendencies of TCS development cause not only significant overview of basic telecommunication concepts but also significant technological drifts as follows [1-3]:

- from speech traffic to data traffic and multimedia traffic;
- from special TCS to global TCS of new generation;

- from local special service to multimedia universal service and applications with guaranteed quality in every time and everywhere.

With consideration of existing tendencies, two scenarios of TCS development are possible: revolutionary and evolutionary. Revolutionary scenario is in a fast substitution of existing electronic TCS development by optical systems with channel capacity about thousands Gb/s. Realization for this scenario requires very big investigations for development and mass production of standardized optical components for global TCS. Evolutionary scenario for TCS development is based on their gradual modernization by advancement of systems, protocols and technology of control for transferred information flows. Today realization of this scenario goes very fast and causes creation of corporative and global TCS of new generations.

Fast grow of real time traffic and its heterogeneous (multimedia) character cause network collisions and overloading, blocking normal TCS work. Rapid development of new kinds of service (electronic commercial, electronic games and entertainment etc.) increased sharply requirements for quality of service (QoS) and information security.

Appeared problems caused necessity for creation of new mathematical models, algorithms of routing and protocols, providing solution of the following tasks:

- development of scaled address system;
- optimization for processes or data flows routing;
- providing of guaranteed quality of service (QoS);
- support and realization of mobile service and Internet.

New tasks and requirements for IP-technologies caused wide use of fourth version of classical protocol (IPv4) and development of its sixth version (IPv6), providing the following [1-2]:

- increase of address field of working part of package till 128 bits, that increases quantity of IP-addresses till 1020 on every TCS node;
- increase of length of package title till 320 bits with information localization, necessary for router work;
- increase of effectiveness by aggregation of addresses and fragmentation of big packages;
- providing of security of information by authentication of nodes-sources and nodes-receivers of information, coding and keeping of wholeness of transferred data.

Architecture of global TCS consists of four basic (basis) subsystems [3]:

1. Distributed communication system (DCS);
2. Network control system (NCS);
3. Distributed information system (DIS);
4. Distributed transport system (DTS).

These subsystems are connected each other and destined for controlled transfer to users of global TCS distributed and computing resources, stored in CS [7-10].

NCS of global TCS of new generation should be adaptive and intelligent [3-11], i.e. have abilities to:

- adaptation (automated self-adjustment) with relation to changing quantity of users, their queries and requirements to quality of provided service, changing structure (topology) of TCS and parameters of nodes and communication channels etc.;
- learning and self-learning for new functions and rules for TCS work;
- self-organization of structure and functions of NCS with dependence on TCS changes;
- prediction for network collisions and other sequences of network control.

Thus, adaptivity and intelligence are the most important features of perspective NCS, destined for regional and global TCS of new generation.

2. Optimization of Traffic Control and Routing of Information Flows

Problem of traffic control in global TCS is decomposed on two interconnected tasks:

1) Planning, optimization and adaptation of routes for flows transfer between TCS nodes;
2) Control of transfer for data flows on defined route with adaptation to changing traffic, possible overloading or changes of TCS topology.

Simplest static setting of task for planning and optimization of data transfer routes is based on suggestion that TCS structure (number of nodes, topology and communication channel cost) is known and constant and TCS internal agent –user is played by one client, forming query to one of node network computers.

Dynamical setting of routing task by user query considers that TCS structure may change with current time but reminds known. At this network information automatically renewals in definite time intervals (Time to Live, TTL), that causes corresponding change of optimal routes.

At adaptive setting of task routing is made in uncertainty conditions, when topology of communication channels and TCS traffic may change unpredictably and accessible information has local character, monitoring and renewal of network information allows to correct routes, adapting them to changing conditions of TCS work (network overloading, failures etc.).

Necessity in dynamical and adaptive routing of data flows in global TCS appears in the following cases:

1) change of cost of TCS communication channel (for example, at their substitution);
2) failure of one or several communication channels in TCS;
3) addition to TCS new communication channels;
4) failure f one or several communication nodes of TCS;
5) addition to TCS new nodes;
6) overloading of TCS communication channels;
7) overloading of buffers of TCS nodes.

In the first case, it is necessary to renewal data about weights (costs) of TCS graph edges, and in the second and third ones – to eliminate or add corresponding edges in TCS graph. In the fourth and fifth cases, it is necessary to change data about TCS nodes by elimination or addition of corresponding nodes in TCS graph. In the sixth and seventh cases corresponding edges and nodes of TCS graph are shown as “prohibited” communication channels and nodes, playing role of unavoidable obstacles for routing and data flows transfer.

Multi-agent setting of task requires development for methods of static, dynamical and adaptive routing in conditions of multi-address transfer and collective use of TCS, when number of external agents-clients of TCS and quantity of their queries may change unpredictably with current time. In this case network overloading and collisions may appear, for their avoidance or resolution special algorithms and tools for their realization are necessary [4-6].

Suggested methods of solution for network control are based on development of adaptive, neural and multi-agent routers, using protocols of new generation (for example, IPv6-protocols).

3. Models and Methods of Adaptive and Multi-agent Routing

Necessity in adaptive routing of data flows appears at unpredictable structure changes (topology of nodes and communication channels) or parameters of global TCS and also at overloading of node buffers or TCS communication channels. Thus routers should plan and correct optimal routes of data package transfer, adapting them to possible TCS changes, appearing in real time.

For that, it is necessary to have feedback communication about current state of nodes and TCS communication channels, which may be organized with the help of monitoring and information exchange between TCS nodes.

Adaptive routing of data flows in global TCS has a series of advantages in relation with non-adaptive (static or dynamic) routing, as follows:

- provides workability and reliability of NCS at unpredictable changes of their structure or TCS parameters;
- causes to more uniform loading of nodes and TCS communication channels by “equalizing” of load;
- simplifies control for data flow transfer at network overloading;
- increases time of dependable work and TCS productivity at high level of provided service at unpredictable changes of network parameters and TCS structure.

Achievement of these advantages depends significantly on used principles, models and algorithms of adaptive routing of TCS data flows with unpredictably changing structure and beforehand unknown traffic.

Principle of adaptive routing with local feedback communication from one node is that data package is transferred into communication channel with the shortest queue or with the most probability of channel preference. At that local equalizing of load in output TCS channels may take place. However, in this case deviation from optimal route is possible. More effective principles of adaptive routing are based on transfer of local information (feedback communication) from neighbour nodes or global information from all TCS nodes. Such information may be presented by data about failures or delays in nodes or communication channels in TCS.

Models and principles of adaptive routing of data flows in global TCS may be divided on three classes [3,5-7]:

- centralized (hierarchical) routing;
- decentralized (distributed) routing;
- multi-agent routing.

Principle of centralized routing is that at first every TCS node transfers information about its state (delay or output channel capacity) to central node-router. Then this router calculates optimal route on the base of obtained global information about current TCS state and transfer it back to all route nodes. After that controlled data package transfer from node-source to node-receiver on planned optimal route begins.

Principle of decentralized routing is based on change of local information between TCS nodes and use of this information about current state of nodes and TCS communication channels for calculation of local-optimal route. As subsequent plots of this route are calculated distributed controlled package transfer from node-source to node-receiver of TCS is realized.

Conclusion

Suggested in the paper mathematical models and optimization methods of dynamical, adaptive, neural and multi-agent (multi-address and multi-flow) routing of information flows for global TCS of new generation are important step towards creation of the theory of adaptive multi-agent (mass) service of global informational and telecommunication networks, which should change traditional theory of mass service. They may be useful for organization of adaptive multi-agent (mass) service of GRID-infrastructure of different scale and destination or for creation of new generation of scientific-educational networks.

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