ADAPTIVE CONTROL AND MULTI-AGENT INTERFACE FOR INFOTELECOMMUNICATION SYSTEMS OF NEW GENERATION

Adil Timofeev

Abstract: *Problems for intellectualisation for man-machine interface and methods of self-organization for network control in multi-agent infotelecommunication systems have been discussed. Architecture and principles for construction of network and neural agents for telecommunication systems of new generation have been suggested. Methods for adaptive and multi-agent routing for information flows by requests of external agents-users of global telecommunication systems and computer networks have been described.*

1. Introduction

Important role for support of “world dialogue” between people and development of man-machine interaction in XXI century will be played by not only global network Internet, but also more modern computer and telecommunication systems (TCS) of new generation. Last years such global TCS are researched and developed in the projects “Internet 2”, “Abilene”, “NGI” etc [1–4].

Design for TCS of next generations requires development of principally new approaches to man-machine interface and network control for information flows on the base of theory of adaptive and intelligent systems, multi-agent and neural technologies and multi-modal systems for virtual reality.

Paper deals with general problems for intellectualization of man-machine interface in multi-agent global TCS and some new methods of multi-agent routing, adaptive control for data flows and network self-organization in dynamical infotelecommunication environment.

2. Architecture for Global Multi-agent Telecommunication Systems

Global multi-agent TCS serve for providing to external agent-users informational and computing resources, distributed in computer networks (CN) around the world. These telecommunication service and information resources are providing to users through multi-agent man-machine interface.

Global TCS architecture is presented in the fig.1. It consists of 4 basic subsystems:

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

All these subsystems are connected between each other and intended for controlled transfer of

Information and computer resources, stored in distributed CS, to agents-users (subscribers, network administrators etc.) of global TCS. Therefore important role in infotelecommunication networks is played by man-machine interface and problems of its modernization.

DCS consists of distributed tools for access and user interface, and also ports and data bus, providing direct and inverse communication between agents-users of global TCS, and connected with it distributed CS, consisting of remote on significant distances computers, local CS, robotic systems etc.

External agents-users of global TCS may be subscribers, administrators, operators and providers of TCS. For its effective interaction with global TCS and CS it is necessary to advance man-machine interface, which is the main part of DCS.

NCS obtains through man-machine DCS subscribers queries and commands of TCS network administrators and processes internal information about current state of DCS and external information about informational and computing resources in CS, coming from DIS.

On this information NCS forms control for data flows in DTS, providing satisfaction for queries of agents-users by address passing to them necessary informational and computing resources of CS.

DIS obtains signals for internal and external feedback about current state of DTS as control plant and accessible informational and computing resources, stored in global CS. It transfers these signals to NCS for forming or correction for control data flow which is going through DTS.

DTS consists of communication nodes (which may be specialized communication processors) and communication channels between them. It plays role of distributed controlled plant and serves for controlled address transfer of data flows from agents-users to CS through TCS and inversely.

All shown subsystems, including man-machine interface of global TCS, have distributed character, are interconnected and interact actively between each other in the process of providing for agents-users informational and computing resources, stored in global CS.

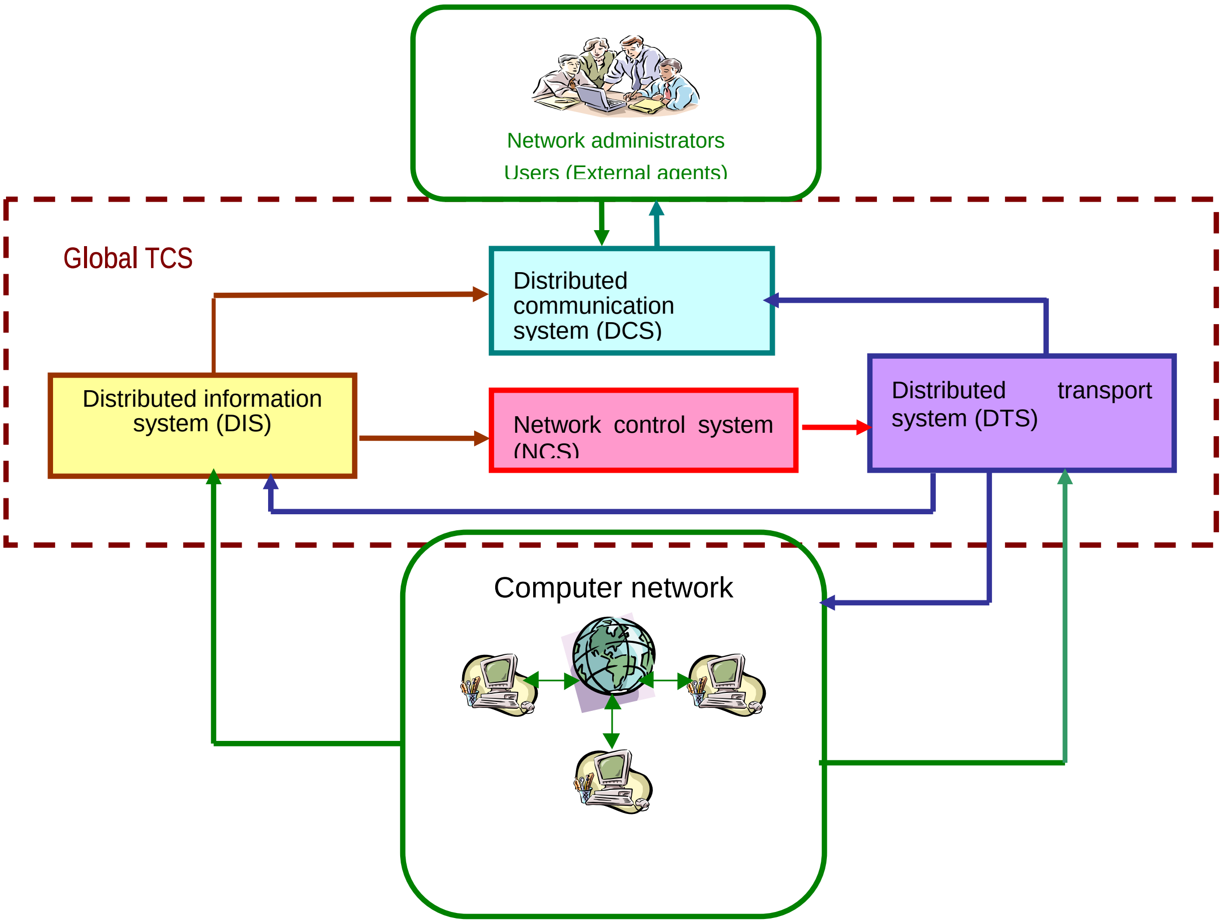

Figure 1. Architecture of global TCN of new generation

3. Self-organization and Adaptation in Network Control

Main role in aiming directed self-organization, adaptive processing of information and address transfer of data flows on the queries of external agents as users of global TCS is played by NCS. Information queries and replies on them are formed with the help of man-machine interface, connecting external agents-users with distributed resources of global TCS and CS.

The main problem for NCS, working on big speeds of data transfer, is self-organization and automatic forming of such adaptive control for data flows in DTS, which supports changing traffic of heterogeneous and multimedia data of great volume with reliable guarantees of high quality of service (Quality of Service, QoS) for external agents-users of TCS.

Decision of this global task for network of adaptive control and self-organization in TCS is divided on local problems of data flows control, adaptation to changing traffic overloading avoidance, network collisions resolution etc. Practical realization of these problems is executed with the help of special network protocols and internal network agents, intended for address transfer of not only informational and controlled signals, but also heterogeneous and multimedia data flows.

In general case shown problems of network control and self-organization should be solved for two main platforms of modern global TCN:

- united IP-networks, interacting through routers of data flows on IP protocol (Internet Protocol) from protocol set TCP/IP (Transmission Control Protocol/Internet Protocol);
- ATM-networks, using protocols ATM (Asynchronous Transfer Mode).

Today these platforms are developed and compete actively on the market of network infotelecommunication service, what is reflected in so called “fight between IP and ATM”. In this connection the significant importance is given to NCS evolution, which will provide convergence and integration of IP- and ATM-networks in global TCS of new generation and their further development.

Traditionally for organization of network control for data flows and DTS equipment network principles and architectures for centralized or decentralized control are used. Every principle has certain advantages and disadvantages.

NCS centralized architecture is based on segregation of central computer, connected through man-machine interface with TCS administrator and executing functions of “control global center” for data flows transfer through nodes and DTS communication channels.

Advantage of such architecture is globality of control from single “centre”. Disadvantages of centralized control are absence of self-organization and low reliability and fault-stability. It reflects in that failure of central controlling computer causes full or partial disappearance of DTS controllability. Therefore reservation of NCS central computer is provided usually. New suggestion is in reservation of also TCN communication channels for multi-flow transferred information.

Decentralized NCS architecture distributes functions for information processing and control between a series of local computers, controlling different segments of DTS or data flows in them.

Advantage of such architecture is that relative independence of distributed “local control centres” increases reliability of address transfer of data flows. Disadvantages of decentralized control are locality and incompleteness of control aims that requires coordination and according work of distributed local controlling computers.

Considering these disadvantages of described traditional network architectures, it is necessary to develop “hybrid” self-organizing architecture of NCS for global TCS of new generation, combinating in itself advantages of centralized and decentralized architectures. Let name such compromise “hybrid” self-organizing architecture of multi-agent architecture of NCS of global TCS.

This new architecture of NCS requires development of theory of internal (network and neural) agents and intellectualization of man-machine interface for external agents-users of TCS.

4. Network and Neural Agents of Global TCS

Basic functions of information processing, self-organization and data flow control on queries of external agents-users of global TCS of new generation are distributed between internal agents. Their role is executed by interconnected network or neural agents of global TCS.

Architecture of these internal agents is presented on fig. 2. Comparing fig. 1 and fig. 2, it may be noted that architecture of global (and also autonomous and local) TCS is analogical (self-similar) to architecture of internal agents. There has appeared fractality of network and neural agents by relation to global TCS in a whole, and also to its most important segment – autonomous and local TCS.

Every internal network or neural agent has own local DB and KB or corresponding neural network (NN) with self-organized architecture and communication tools (communication channels, protocols etc.) with other agents for information exchange in process of joint (cooperative) decision making, self-organization “by interests” and automatic forming of network control of DTS, providing addressed delivering of informational computing resources of CS on the queries of external agents-users of global TCS.

Network or neural agents of TCS may be communication computers or neural routers of NCS, connected with DTS nodes, and also software or software-hardware Bagents of DCS and DIS, connected with intelligent man-machine interface of global TCS. Such internal agents of global TCS of new generation differ significantly from external agents-users of TCS (subscribers, network administrators and operators etc.), using tools for access and network man-machine interface for own informational queries to computer nodes (hosts) of distributed CS and obtaining replies on these queries.

Agents accumulate or generate in themselves local DB and KB, necessary for making of effective (particularly, optimal) decisions and executing of corresponding local operations in the limits of own (local) “competentness”. For communication between each other agents use corresponding “communication language”, including certain “dictionary store”, presenting formats and protocols for data transfer etc. Agents are able to solve independently local decisions and provide their execution.

So they can solve arising tasks both autonomously and collectively. For collective solution of tasks the agents may cooperate and self-organize in working groups “by interests”. Such group will be named agencies, having certain specialization, defined by agent interests, in corresponding problem (plant) area.

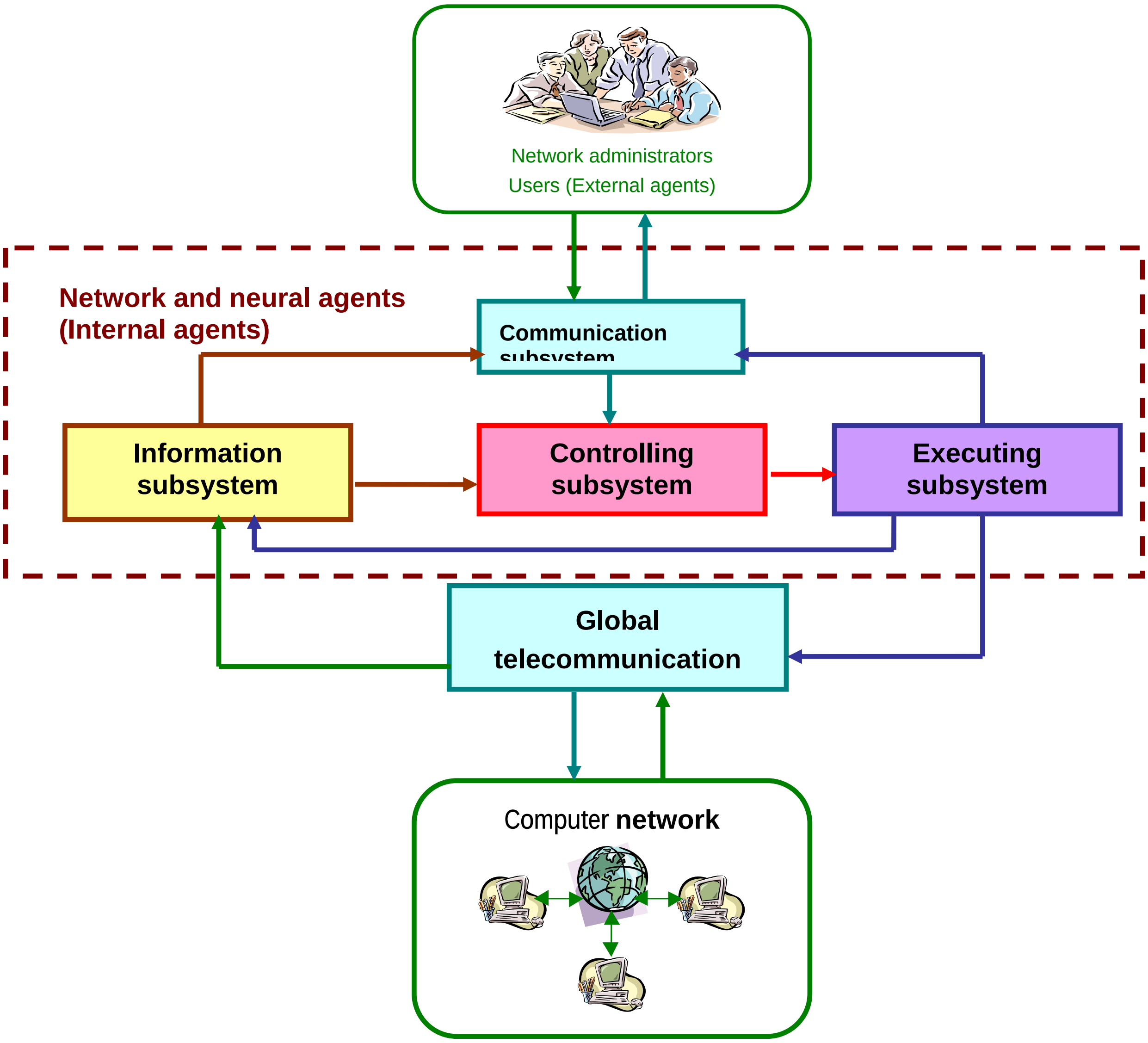

Figure 2. Architecture of network and neural agents in global TCS of new generation

Structure (architecture) and functions (operations) of agent are able to support initially interaction of its four basic subsystems between each other and with environment. However during concrete problem decision agents may be learned and extend their local DB, be adapted to changing or uncertain function conditions and exchange knowledge with other agents. Such learning agents are in fact adaptive developing intelligent systems. Their functional possibilities and intelligent abilities are extended during “vital cycle”, i.e. as learning and experience accumulation.

Neural agents are intended mostly for parallel transfer and processing of complex signals and images. They are mostly 2D- or 3D-images and vector signals. Set of such signals with information about their belonging to different classes of patterns makes experimental data bases (DB). These DB are named learning DB, because they are used for learning and self-organization of neural agents. In result there is adjusting of architecture (topology of network neurons) and parameters (synaptical weights) of neural agents to solved problem by a set of learning precedents.

Non-linearity of functions for neurons activation plays important role in it. These functions may be threshold or sigmoidal, polynomials or conjunctions etc. If these functions are linear, all neural network of agent makes only linear transformations of vector or matrix of internal signals, that corresponds to single-layer neural network. However superposition of non-linear neurons

extends significantly computing and intelligent possibilities of neural agents both local (concentrated), and global (distributed) learning DB.

During design for NCS and intelligent man-machine interface on the base of theory of agents and principles of self-organization new problems of multi-flow routing and multi-agent dialogue between internal agents of global TCS of new generation, external agents-users and server agents-informators of global TCS as distributed world store for data, knowledge and applications arise.

Decision of these problems requires development for methods of self-organization and adaptation, including in itself tools for avoidance or automatic resolution of network collisions between agents under control of intelligent NCS of global TCS with multi-agent architecture.

For controlled address transfer and navigation of data flows, functional diagnosis and recognition for states of global TCS of new generation it is necessary to introduce special internal agents-coordinators (for example, on level of data flow routing) and, possibly, other global agents, providing self-organization and adaptation in process of man-machine interaction and decision making.

Singularity of these coordinating agents of high level is that their DB and KB are formed on the base of local DB and KB of agents of lower level. Therefore they have global (multi-agent) character and allow to evaluate network situation and provide self-organization “as a whole” by queries of external agents-users of global TCS.

Thus, development of man-machine interface and advancement of self-organizing architectures of NCS of global TCS of new generation should be done not only and not so much “in a width”, i.e. “by horizontal” territory envelope, but mostly “in a depth”, i.e. “by vertical” of evolution for hierarchy of network control and self-organization.

Processes of adaptation, self-organization and intellectualization play important role both in NCS and TCS, and in multi-agent man-machine interface.

5. Multi-agent Interface and Problems of Adaptive Routing of Information Flows

Multi-agent interface of global TCS of new generation is necessary for organization of effective interaction of external agents-users of TCS and internal network or neural agents. Here important role is played by intelligent man-machine interface, providing interaction and cooperation “by interests” of external agents as users of global TCS

This man-machine interface is based both on own DB and KB of agents-users, and distributed local and global DB and KB of TCS and CS. It serve for forming of set and sequence of addresses of sources and receivers of the information, which play role of concrete aims of network control of multi-agent address transfer of data flows on queries of external agents-users of TCS.

Let discuss basic singularities of network control and importance of processes of adaptation and self-organization on the example of adaptive multi-agent routing of information flows and global TCS [5–9].

Necessity in adaptive routing arises at unpredictable changes of structure (nodes and communication channels) of TCS or at overloading of node buffers or channels of TCS. Routing and self-organization of information flows in non-stationery global TCS with variable structure and known beforehand load is discussed actually.

Causes of TCS structure changing may be both addition or failure of different nodes and communication channels and network overloadings, which prevent transfer of data flows through forbidden (overloaded) nodes and channels. That is why router should plan and correct optimal routes of transfer of data packages, adapting them to possible TCS changes, happening in real time. For it feedback about current state of nodes and TCS communication channels, which may be organized by information exchange between TCS nodes, is necessary.

Distinctive features of adaptive routing in comparison with traditional routing static or dynamic routing are the following peculiarities [6-8]:

- algorithms for adaptive routing requires consideration and processing of current information about TCS, that makes them more complex and increase optimal route definition time;
- transfer of information about state or structural changes in TCS to adaptive routers loads additionally a network and causes delays (lags);
- increasement of network load and time of delay may cause oscillations or auto-oscillations and increase a number of steps at determination of optimal route.

Adaptive routing of data flows in global TCS has a series of advantages relatively to non-adaptive (static or dynamic) routing and precisely these:

- provides workability and reliability of TCS at unpredictable changes of their structure or parameters
- causes more uniform load of nodes and TCS communication channels by “smoothing” of load;
- simplifies control for transfer of data flows and make more easy adaptation to network loads;
- increase time for infallible time and productivity of TCS at high level of rendered service in unpredictable conditions of changing of network parameters and structure, that is important essentially for external agents-users of TCS

Reaching of these advantages depends significantly from used principles and algorithms of adaptive routing and self-organization of data flows in TCS with unpredictable structure and traffic, unknown beforehand [4–10]. It is important note that “adaptive routing is a problem, which is rather difficult for proper solution” [1].

6. Methods for Adaptive and Multi-agent Routing of Information Flows

Principles of adaptive routing and self-organization of data flows may be divided on three classes in dependence from used information about real (current) state of global TCS, i.e. from character of feedback signals [4–6]:

- local information (feedback) from one node of TCS;
- local information (feedback) from node and its “neighbours” in TCS;
- global information (feedback) from all three node of TCS.

Simplest principle of adaptive routing with local feedback form one node is that data package transfers to communication channel with the most short queue or with the biggest probability of channel preference. Local load smoothing in output channels of global TCS may be happen. However in this case it is possible to deviate from optimal rout.

More effective principles of adaptive routing are based on transfer to initial node a local information (feedback) from neighbour nodes or global information from TCS nodes. As this information data about failures or delays in nodes or communication channels in TCS may be used.

In dependence on used ways of processing for local or global information (feedback) principles of adaptive routing may be divided on three classes:

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

Principle of centralized routing is that every node of TCS transfers in first an information about own state (delays or external channels capacities etc) to central router. Then this router computes optimal rout on the base of obtained global information about current state and passes it back to all TCS nodes. Then controlled transfer of data packages from node-source to node-subscriber of TCS by planned optimal rout.

Principle of decentralized (distributed) routing is based on information exchange between TCS nodes and using of this information about current state of nodes communication channels of TCS for optimal rout calculating. As calculating of sequent plots of this rout distributed-controlled package transfer from node-source to node-receiver of TCS is executed.

Principle for multi-agent routing and self-organization of data flows is distinctive compromise between principles of centralized and decentralized routing. It is based on multi-agent man-machine interface and multi-address and multi-flow routing and analysis of possible network collisions with aim to eliminate them or to resolve during optimal data transfer by a set of optimal routes from nodes-sources to nodes-receivers of global TCS. More thoroughly this principle and concrete methods of multi-agent routing have been discussed in works [2–9].

7. Multi-flow Routing as Tool of Increase of Reliability of Global Telecommunication Networks

Main disadvantages of single-flow routing in global dynamic TCS are its following peculiarities :

- fault or failure of at least one node or TCS communication channel, through which optimal rout for data package transfer passes, require hard replanning (recalculating) for optimal rout (or its part) with consideration of faulted nodes or communication channels;
- planned rout between any defined node-source and node-receiver of TCS may cause network overloadings in the time, when other (for example, neighbour) nodes and communication channels may be free or not fully loaded.

First disadvantage causes great delays at controlled transfer of data flows, connected with information renewal about TCS state and recalculating of new rout. Such delays (lags) are not accessible for high-quality QoS–service of TCS users' queries or transfer of multi-media real time traffic.

Second disadvantage causes also delays because of overloading of nodes or communication channels, which are in optimal rout. At it a network traffic is distributed non-smoothly, so many intermediate nodes and communication channels of TCS are not loaded or simply are not used.

To overcome difficulties, connected with noted disadvantages, it is useful to use multi-flow routing. It is planned and used simultaneously not one (for example, optimal) rout of data package transfer, but $K \geq 2$ routes. More K is, more probability of data package delivering to node-source to node-receiver is. Consequently reliability and fault-stability of TCS are increased.

At centralized multi-flow routing an apriori planning of $K \geq 2$ optimal or suboptimal routes by existing (fixed) or renewal information about TCS state is made. Parallel use of these uncrossed routes provides more reliable delivering of data packages form node-source to node-receiver. At this case network traffic is distributed on TCS more smoothly, that decreases influence of possible overloadings in separate nodes or communication channels.

At decentralized (distributed) routing in the newt node of rout, it is planned $K \geq 2$ optimal or suboptimal routes of data packages transfer to node-receiver. Such method of aposteriori planning of K-routes "from reached node" requires special mechanism (closed routes) at package data transfer.

The main advantage of the method of aposteriori K-routing is that it provides automatic "avoidance" of failured of fault nodes or TCS communication channels. Other advantage is connected with local detection of faulted nodes or communication channels. It allows to renewal fast an information about TCS current state and insert necessary corrections to tables and routing maps.

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Author Information

Adil V. Timofeev – Saint-Petersburg Institute for Informatics and Automation of Russian Academy of Sciences, Head of the Neural Informatics and Intelligent Control Laboratory; 199178, Russia, Saint-Petersburg, 14-th Line,39, e-mail: tav@iias.spb.su