Space Experiment "Kontur-2": Applied Methods and Obtained Results

Vladimir Muliukha[1,2], Aleksandr Ilyashenko[1], Vladimir Zaborovsky[1,2], Andrey Novopasheniy[1]
[1]Peter the Great St.Petersburg Polytechnic University, Saint-Petersburg, Russia
[2]Russian State Scientific Center for Robotics and Technical Cybernetics, Saint-Petersburg, Russia
vladimir@mail.neva.ru, ilyashenko.alex@gmail.com, {vlad, andr}@neva.ru

***Abstract*—Space experiment "Kontur-2" aboard the International Space Station is focused on the transfer of information between station and on-ground robot. Station's resources are limited, including communication ones. That is why for the space experiment "Kontur-2" it was decided to use the methods of priority traffic management. New access control mechanisms based on these methods are researched. The usage of the priority traffic processing methods allows using more efficiently the bandwidth of receiving and transmitting equipment onboard the International Space Station through the application of randomized push-out mechanism. The paper considers methods applied for traffic management and access control during international space experiment "Kontur-2" performed aboard the ISS. The obtained results are also presented.**

I. INTRODUCTION

Access control to the network resources is an important task of the information security. Especially it is necessary for the advanced modern space applications, for example during space experiments onboard the International Space Station (ISS). Such digital resources have to be available for authorized usage by cosmonauts and the mission control center, and protected against unauthorized access. In the modern computer networks, including ISS onboard network and satellite communicational channels TCP/IP stack is used. That is why the informational interaction between nodes is occurred using application protocols over virtual transport connections.

As the result, the problem of traffic management and access control can be presented as the task of identifying the characteristics of virtual connections and traffic control using virtual connection content code. This code is calculated according to the connection content and it shows the requested quality of service (QoS). The complexity of this problem is the fact that the content code can be calculated exactly only after the virtual connection is finished. However, in this case, the access control problem cannot be solved, because the access becomes irreversible.

The paper considers methods of dynamic priority traffic management and access control methods that have been used in international space experiments performed aboard the ISS. The proposed methods are probabilistic, but they could improve the effectiveness of information traffic management by various control throughput mechanisms of such virtual connections.

To solve the problem of calculating the dynamic content code we consider to use the indicator function, whose properties depend on: the information model of the network resource and the description of the access policy, which defines the rights of users and QoS requested by virtual connection (VC).

In this paper, we propose a new approach to access control flexibility enhancement based on active queuing management mechanism and randomized preemptive procedure. In "Kontur-2" space experiment, the offered solution was implemented by the access gateway – specialized device, based on hardware firewall that realizes several functions:

1) organization of informational interaction between robotic devices;
2) communication with operator;
3) traffic management;
4) enforce security policy.

The access gateway is a two-component device. The first part is the firewall, and the second one is the security server, which generates access rules and enforces the access policy. The adaptability of the proposed mechanism improves network security, but it requires large computational resources of the access gateway. That is why the security server was realized using cloud technologies. Security server analyzes network traffic and generates access rules for firewall considering current state of connections, available resources of internal network, and access policy.

The parameters of access gateway (firewall) rules depend on the set of network environment and/or protocols characteristics A. This set can be divided on two classes with different access conditions. In proposed approach the classification decision is based on access code F and firewall has three modes in accordance to possible F (A) values (Fig. 1):

- "–1", if the data flow is forbidden according to the access policy (filtering rules);
- "1" and "0" for permitted VCs.

The state of the virtual connection is controlled throughout its lifetime. When the network environment is congested or when VCs have different QoS requirements the subset of permitted connection has to be divided into new subsets with different access codes:

- "1" for prior VCs that have low throughput and demand low stable delivery time;

- "0" for background ones that demand high throughput and have no delivery time requirements.

For more accurate data sorting we propose to use multiple priority levels. In our space experiment, we consider the simplest situation with two priority levels (control commands and video data). But it may be not enough for some practice tasks so we propose some easy ways to increase the number of levels using subsets of permitted VCs (see Fig. 1).

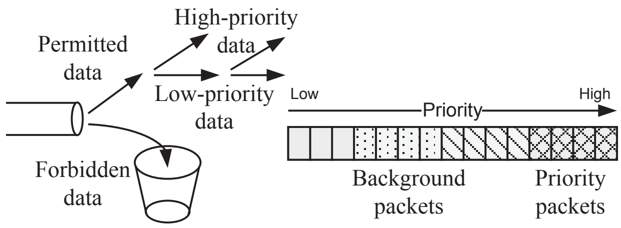

Fig. 1. Multiple priority level in congested operation networks

To provide this classification procedure we have proposed active queuing management mechanism, which based on randomized preemptive control [1][2]. Therefore in the firewall, the data flow throughput and time that packets spend in queue (minimum value for priority permitted flows and infinity for denied) are the functions of randomized control parameter .

In the space experiment "Kontur-2", we used the Access Gateway with the architecture described in [1]. This architecture includes several modules: Network Monitor, Access Policy Description Module, Information Resource Module, Firewall Rules Generator and Firewall that implements the rules and manages the traffic flows.

The paper is organized as follows: Section II describes the priority queueing model and basic equations. Section III is about the information flows in space experiment "Kontur-2". Sections from IV till VI are about practical application of proposed method in space experiment "Kontur-2" and obtained results in different sessions. Section VII is devoted to our future plans. Section VIII concludes the paper.

II. Model of Network Environment

According to the VC models written above we consider the preemptive priority queueing system with two types of packets. First type of packets has priority over the second one. The packets of the type 1 (2) arrive into the buffer according to the Poisson process with rate λ_1 (λ_2). The service time has the exponential distribution with the same rate μ for each type. The service times are independent of the arrival processes. The buffer has a finite size k ($1 < k < \infty$) and it is shared by both types of packets. The absolute priority in service is given to the packets of the first type. Unlike typical priority queueing considered system is supplied by the randomized push-out mechanism that helps precisely and accurate to manage packets of both types. If the buffer is full, a new coming packet of the first type can push out of the buffer a packet of type 2 with the probability α.

The summarized entering stream will be the elementary with intensity $\lambda = \lambda_1 + \lambda_2$. Using the Kendel notation modified by Basharin, proposed system has $\vec{M}_2 / M / 1 / k / f_2^1$ type [3].

Problems of research priority queueing have arisen in telecommunication with the analysis of real disciplines of scheduling in operating computers. During the last years, a similar sort of queueing model, and also their various generalisations are widely used at the theoretical analysis of Internet systems.

As shown in [3], the probability pushing out mechanism is more convenient and effective in comparison with other mathematical models of pushing out considered in the literature. It adequately describes real processes of the network traffic and is simple enough from the mathematical point of view. The randomized push-out mechanism was proposed in [4] but in our work we used it for a new task of traffic control. The other control and security factor is the telematics device buffer size. It can be varied to increase the throughput of necessary connections and reduce throughput of suspicious ones.

The state graph of system $\vec{M}_2 / M / 1 / k / f_2^1$ is presented in Fig. 2.

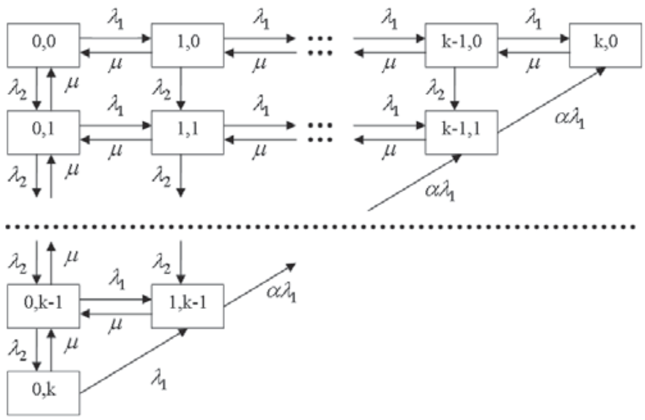

Fig. 2. The state graph of $\vec{M}_2 / M / 1 / k / f_2^1$ type system

Making by usual Kolmogorov's rules set of equations with the help of state graph we will receive:

$$
\begin{aligned}
&-[\lambda_1(1-\delta_{j,k-i}) + \alpha\lambda_1(1-\delta_{i,k})\delta_{j,k-i} + (1-\alpha)\lambda_1\delta_{i,0}\delta_{j,k-i} + \\
&+\lambda_2(1-\delta_{j,k-i}) + \mu(1-\delta_{i,0}\delta_{j,0})]P_{i,j} + \mu P_{i+1,j} + \mu\delta_{i,0}P_{i,j+1} + \\
&+\lambda_2 P_{i,j-1} + \lambda_1 P_{i-1,j} + \alpha\lambda_1\delta_{j,k-i}P_{i-1,j+1} + \\
&+(1-\alpha)\lambda_1\delta_{j,k-i}\delta_{i,1}P_{i-1,j+1} = 0, (0 \le i \le k; 0 \le j \le k-i),
\end{aligned} \quad (1)
$$

where $\delta_{i,j}$ is the Kroneker's delta-symbol.

There is a normalization condition for the system:

$$\sum_{i=0}^{k}\sum_{j=0}^{k-i} P_{ij} = 1 \cdot$$

At real k (big enough) this system is ill-conditioned, and its numerical solution leads to the big computing errors. We used the method of generating functions, which is discussed in detail in [2] and [3]. According to generating function method and normalization condition we have:

$$G(u,v) = \sum_{i=0}^{k}\sum_{j=0}^{k-i} P_{i,j} u^i v^j, \quad G(1,1) = \sum_{i=0}^{k}\sum_{j=0}^{k-i} P_{i,j} = 1$$

And after several transformations [1]-[3], solving (1) system we receive loss probability for priority ($P_{loss}^{(1)}$) and non-priority ($P_{loss}^{(2)}$) packets:

$$P_{loss}^{(1)} = q_k + (1-\alpha)\sum_{i=1}^{k-1} p_i, \qquad (2)$$

$$P_{loss}^{(2)} = r_k + \alpha \frac{\rho_1}{\rho_2}\sum_{i=1}^{k-1} p_i + \frac{\rho_1}{\rho_2} p_k \qquad (3)$$

where $p_i = \begin{cases} P_{i,j} \\ i = j = \overline{0,k} \end{cases}$, $q_i = \sum_{j=0}^{k-i} P_{i,j}$, $r_m = \begin{cases} \sum_{i,j=0}^{m} P_{i,j} \\ i+j=m \end{cases}$.

The loss of packets is caused by the buffer overflow of intermediate network devices, which in our model is represented in the form of a queue overflow. Exploring formulas (2) and (3) we found some useful properties of this system described in this article. When incoming stream of priority packets getting more intensive, system starts to prohibit admission of non-priority packets. While the total flow rate is less than unity ($\rho_1 + \rho_2 \le 1$), the probability of loss is equal to zero. This means that the system is fully copes with the load.

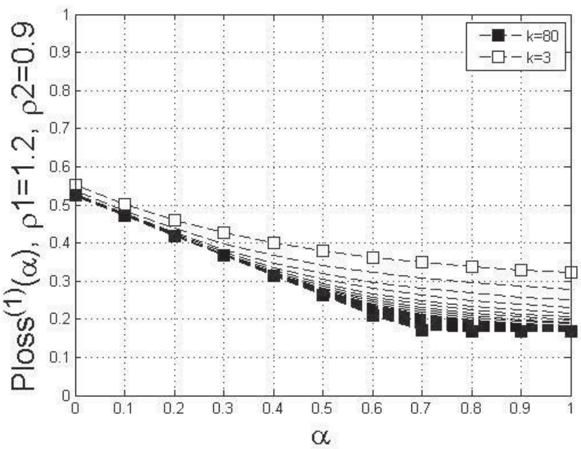

Fig. 3. Loss probability of priority packets with buffer size K=3-80

In Fig. 3 an expected result can be seen that the probability of losing priority packet decreases with increasing size of a buffer. Probability of loss is not decreasing more than 5% for small values of α. Therefore, only for large probability values increasing buffer size effectively influences the losses. For priority stream influence of this effect is the same for all values of alpha, but for non-priority packets the situation is different. Fig. 4 shows that it is sometimes advantageous to have a buffer of smaller size. With a small buffer probability of be pushed out much lower, what explains this effect.

Graphs of the relative throughput which is computed by formulas (4) are very important for research of processes in computer networks.

$$æ_i = 1 - P_{loss}^{(i)}, \quad (i = \overline{1,2}). \qquad (4)$$

From formulas (2) and (3) we can see that by choosing parameter α, we can change $P_{loss}^{(2)}$ in very wide range. For some ρ_1 values variable $æ_i$ changes from 0.7 to 1 while $\lambda_1 + \lambda_2 >> \mu$.

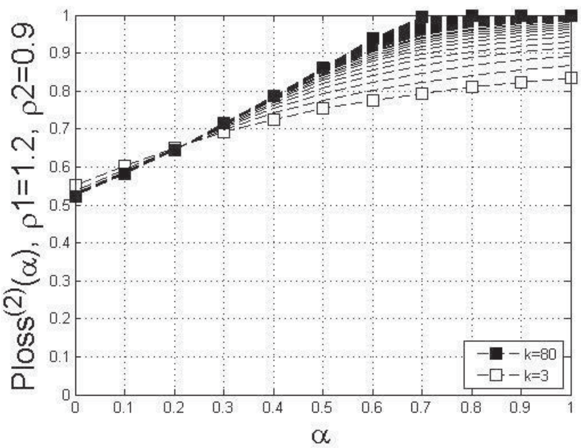

Fig. 4. Loss probability of non-priority packets with buffer size K=3-80

In [2] and [3], we have calculated different variable like average queue length of priority packets and the relative time that the priority packet spend in queueing system. So the α parameter is strong enough to influence the filling of the queue.

In [3] it is shown that proposed queueing mechanism provide a wide range of control feature by randomized push-out parameter α and buffer size k. According to the packet's mark (Forbidden, Priority, Background) the period that packet spend in queue can vary from 1 to 10^{14} times, which can be used to enforce requested QoS for traffic. For highly congested network the priority type is much less important, than the push-out mechanism and the value of α parameter. The push-out mechanism allows enforcing access policy using traffic priority mechanism.

By choosing α parameter we can change the time that packets spend in the firewall buffer, which allows to limit access possibilities of background traffic. So by decreasing the priority of background VCs and increasing the push-out probability α we can reduce the VC throughput to low level without interrupting it.

The most wide range of control can be reached in intermediate environment conditions when linear law of the losses has already been broken, but the saturation zone has not been reached yet. Numerical experiment [3] has been made to detect conditions in which ρ_1 varied over a wide range from 0,1 to 2,5, and few fixed values for ρ_2.

An application of the Alternating Priorities Queueing System for problems of our class are considered in the [5].

III. Scheme and Information Communications of the Space Experiment

Good example of practical application of such mechanism is the problem of controlling remote robotic object, which telemetry data and a video stream are transmitted on global networks [6][7]. In this case, control commands are transmitted by TCP, and a video stream data are transmitted by UDP. A mean values of throughput of our robotic object: throughput of TCP channel (control and telemetry packets) ~100Kb/s, throughput of UDP video stream ~1,2Mb/s.

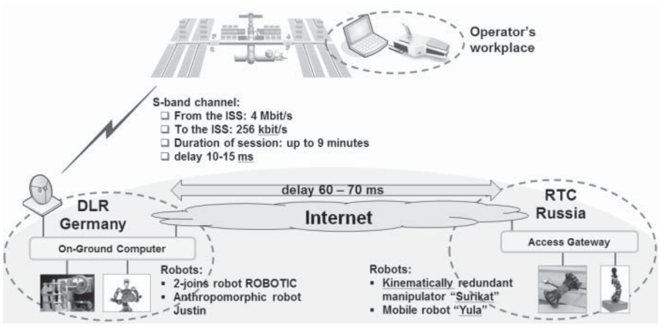

Fig. 5. The scheme of space experiment "Kontur-2"

In a considered example from Fig. 5, in the space experiment "Kontur-2" [7], as well as in a previous space experiment "Kontur" [8], the choice of a priority mechanism and a parameter of loss-probability for a priority packet α allows to balance such c of functioning of a network, as loss-probability of control packets $p_{loss}^{(1)}$ and quality of video stream for various conditions of a network environment. The parameter α can vary for delay minimization in a control system's feedback.

The problem of traffic control and management, including security and QoS is as old as communication networks are. There are different solutions like IntServ (RFC 1633) and DiffServ (RFC 2474, 2475). The presented solutions require the support of protocols in the intermediate nodes for successful work. Our network consisted of two segments. One is the segment from DLR to ISS, and the second is from DLR to RTC. The first was completely under our control. Within the second, it was necessary to propose methods for controlling information flows in end nodes without access to all intermediate equipment. A software solution for these purposes was developed on the basis of the existing equipment for filtering the traffic – SSPT-2 firewalls. During the software development and crew training sessions, the connection with the State Organization "Gagarin Research&Test Cosmonaut Training Center" (GCTC) and RSC Energia were conducted with the help of the Check Point IPSEC VPN server, which was provided by colleagues from RSC Energia.

The given problem is important for interactive control of remote real-time dynamic objects, in a case when the complex computer network is the component of a feedback control contour, therefore minimization of losses and feedback delays, is the important parameter characterizing an effectiveness of control system.

The same traffic management system shown in Fig. 6 is used in space experiment "Kontur-2", where the operator is onboard ISS and robotic system is on Earth surface in Saint-Petersburg, Russia and in Munich, Germany.

During the space experiments "ROKVISS" and "Kontur" that were minutely considered [1][7]-[9], it was established that an important component of effective remote control for robotic object is a high degree of "dipping" of the operator in the robot's functioning environment [9]. Thus a telepresence for operator in such an environment is ensured by outputting a video stream coming from the camera of the robot into a workplace of operator-cosmonaut. Simultaneously the tactile capabilities of the robot are reproduced by the special joystick, which is connected with the operator through man-machine interfaces with the force-torque feedback. That is why the development of the space experiment "Kontur" was considered a study on the effect of weightlessness on the opportunity of operator-cosmonaut to control remote robots using force-torque joystick. The necessity to send the equipment, which will interact with the cosmonauts onboard ISS gives us new requirements for reliability and security for all systems' components, including communication channels.

An actual scientific and technical problem of the new space experiment "Kontur-2" is the creation of methods and development of the technology for remote control on-surface robots and robotics groups from orbiting spacecraft for solving planetary exploration.

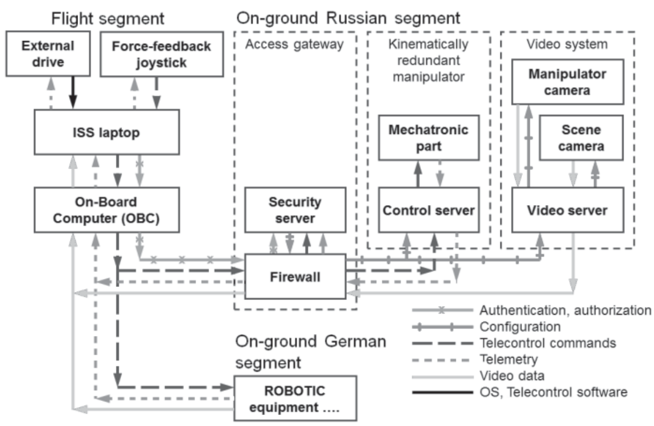

Fig. 6. Functional scheme of space experiment "Kontur-2"

The ability to effectively control robots on the surface of planets from a manned orbital spacecraft is determined by the following factors:

- reliability of telecommunication channels used for transmitting control commands, telemetry and video data between an operator and robot, their capacity for reconfiguration and scalability;
- performance of communication channels in order to minimize the delay of transmitted data;
- adequate response of the operator in weightlessness to the impact from the joystick with force-torque feedback, taking into account the time delays and discontinuity of video feedback received from the controlled robotic object.

The study of these factors significantly differs this work from the previous ones [7],[9].

IV. DLR EXPERIMENT

In DLR mission of "Kontur-2" experiment, two scenarios had to be considered in the design of the bilateral joystick controller: ISS and training. The first is the nominal mission case, where the cosmonaut controls the robot from the ISS through the S-band link. The second one is a geographically distributed scenario through the Internet for cosmonaut training purposes (see Fig. 5). Since the exact same system needs to operate in both, the requirements for the bilateral controller are clearly strengthened as both links are characterized by different communication parameters.

The nature of these two links is quite different in terms of time delay, data losses and jitter. The time delay for the ISS communication varied from 20 to 30 ms (corresponding to azimuth and horizon points) with mean negligible data losses. The internet training setup introduced a mean delay of 65 ms between Star City and Oberpfaffenhofen (where the DLR is located) and highly oscillating package loss ratio, from 5% to 15%, due to the UDP protocol. Though more limited in bandwidth, the ISS link had low delay and packet loss probability during the transmission. However, shadowing can occur resulting in signal attenuation and in turn higher package loss ratios or even communication blackouts. On the other hand, the internet link measurements confirm a typical UDP behavior.

During the DLR sessions, cosmonauts controlled the ROKVISS arm, located in one of the laboratories in Oberpfaffenhofen. The approach for the bilateral controller in the force-feedback joystick is based on a 4-Channels architecture, whose stability in the presence of time delay, jitter and data losses is addressed through the Time Domain Passivity Control Approach (TDPA) [10] and the Time Delay Power Network (TDPN) representation. In this architecture, position and force signals are sent from the joystick to the ROKVISS robot, and computed and measured force signals are sent in the other direction. Both systems, the joystick and ROKVISS, are impedance controlled, i.e. the commanded signals to the joystick and to the robot are forces, and their outputs are positions. Interestingly enough, the same controller parameters were used in both described scenarios, that is, mission (ISS S-Band link) and training (internet DLR – GCTC). Indeed, one of the most interesting features of this controller is its adaptability to any communication conditions, including different delay values, jitters and package losses.

The experiments with the joystick on board the ISS proved that all hard- and software components of joystick as well as the telepresence system are functioning reliably. The joystick is able to provide stable and reliable force feedback performance thanks to its fast real time interface and low intrinsic latencies. These hardware and software components have been validated in the space experiment "Kontur-2". The participating cosmonauts, Oleg Kononenko and Sergey Volkov, were able to perform the experimental tasks with the ROKVISS robot, located in the DLR in Oberpfaffenhofen (Germany) from the Russian Segment of the ISS. Force-feedback and latency compensation technologies for bilateral control were successfully evaluated [11]. The cosmonauts reported that the tasks were easy to perform with the force feedback joystick. Different telepresence approaches were compared in terms of system and operator performance and the results from terrestrial and space sessions were compared to better understand the effects of microgravity on sensorimotor performance while controlling a telerobotic system. Preliminary analyses revealed that positional accuracy is degraded in microgravity compared to terrestrial conditions. Yet, these performance losses can partially be compensated by implementing a movement damping at the joystick. One of the most interesting features of the bilateral control approach based on the Time Domain Passivity Approach is that a system tuned for a setting close to ideal can operate in the ISS communication conditions and the internet training setup with guaranteed stability.

In more detail, the DLR part of the experiment is considered in [11].

V. RTC EXPERIMENT

During first part of RTC experiment cosmonauts from onboard the RS ISS controlled cinematically redundant manipulator Surikat which equipped stylus and light targets located around [1][7]. Targets lighted up for a short time and the cosmonaut had to extinguish the target, touching it by the stylus. Unlike DLR's robot Surikat didn't have torque sensors so force feedback on the joystick handle reflected the current position of the robot so that operator cannot move the handle faster than the robot has reached already specified position taking into account the delay and inertia of the robot.

Unlike DLR experiment during RTC control sessions connection to the ISS took place not only via S-band link, but also through the Internet (see Fig. 5). This imposes additional restrictions on the control system, such as increased delays, a high percentage of packet loss and higher jitter as showed above. Nevertheless established telecommunication infrastructure provides transmitted transmission heterogeneous traffic with an acceptable quality of service for each of the control channels, and feedback. The most critical to latency and bandwidth bi-directional control channel provided total transmission delay for the control and feedback loop (round trip time - RTT) about 85 ms. Fig. 7 shows a graph of RTT for RTC session. The graph shows the change of RTT during the sessions which is connected to change in distance between ISS and ground station.

Established control system provided manual teleoperation from the ISS RS of robots located on Earth. Operator onboard the ISS RS receives feedback from the robot through several channels:

- Tactile feedback provided by transfer of information between robot and joystick drives controllers. Minimum delay for this type of feedback is provided by operation of controllers in real time and transmit this information flow via priority channel in S-band link. This type of feedback provided to the operator a tactile information about the inertia of the system in the absence of a torque sensor on the robot;
- Visual feedback, obtained by translation of the video from a camera mounted on the robot, or from the observation camera. For this type of feedback it was defined the balance between the quality of the transmitted image, the frequency of its update and delay in delivery when there are significant limitations on the bandwidth of the communication channel (256 kbit/s for upload). Since we used data compression algorithms, the feedback on video data had an appreciable delay due to data processing at the transmitting and receiving computers;
- Visual feedback, obtained by visualization of the robot's 3D-model motion on the laptop. During control of Surikat for animation of 3D-model it was used telemetric information from the robot. This information was delivered in the priority channel, which provided low delays in display. Compactness of transmission data allowed for a low bandwidth to provide higher image refresh rate (compared to video), which significantly improves the dynamic picture representations of the surrounding area.

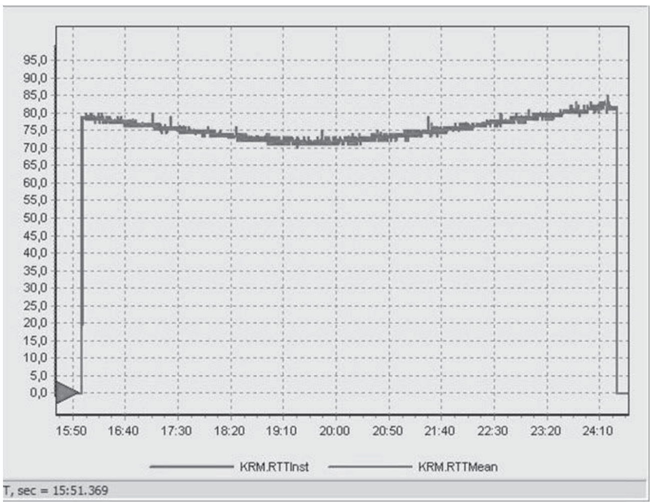

Fig. 7. RTT between the ISS and RTC during the space experiment

The effectiveness of combination of several types of feedback – haptic (force in the handle of RJo) and visual (video and 3D- model) – complement each other to provide a virtual "immersion" of operator to the environment of the robot operation, confirmed the successful implementation of manipulation and locomotion tasks carried out during teleoperation sessions.

Force feedback joystick was used in the experiment as part of different teleoperation systems for control heterogeneous robots. Software architecture allowed choosing the controller of RJo depending on the current session (DLR or RTC) and dynamically changing its settings during a session.

For teleoperation of RTC Surikat robot it was used dual-channel architecture with controllers, designed in RTC: the information about current position transmitted between RJo and the robot. RJo controller allowed implementing a virtual spring on the handle, which bind the position of the RJo handle and robot. Furthermore, it provided sensitive of virtual mass and viscosity. The insertion of force feedback to control of the robot, which doesn't have force-torque sensors, yield positive results like an increased speed and accuracy of operations. Fig. 8 shows the trajectory of RJo and Surikat in the absence and presence of force feedback while performing the same tasks in experiment session.

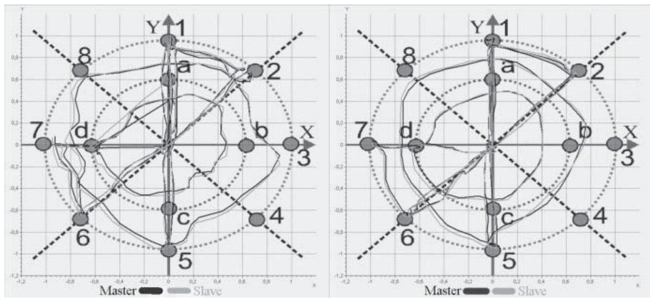

Fig. 8. Trajectory of RJo's handle (Master) and Surikat (Slave) in the absence (left) and presence (right) of force feedback

When the force-feedback is used to remote control of robots, in addition to the requirements for communication channels, in microgravity conditions there are also requirements to the workplace of operator-cosmonaut. Fig. 9 shows a photo of cosmonaut Oleg Novitsky that was made during the control of mobile RTC robot in December 2016. During the control sessions, cosmonauts have to hold a special hard handle with their left hand so not to lose the balance under the force impact from the joystick.

Fig. 9. Cosmonaut Oleg Novitsky controls the mobile RTC robot

VI. Sessions of RTC mobile robot control

In 2016, additional sessions of the space experiment “Kontur-2” were organized to realize operations for remote control of the mobile robot from the ISS RS. To conduct these sessions, a specialized mobile robot and a three-dimensional polygon were created. The experiment used a model-based feedback and cyber-physical method of representation of a robotic system [7][12][13]. The essence of this type of feedback is that the force-torque actions on the handle of the joystick onboard the ISS are calculated in the program based on the current position of the obstacles, the robot, its speed and direction of movement. Thus, the model-based feedback increases demands on the accuracy and speed of the robot’s positioning system [7].

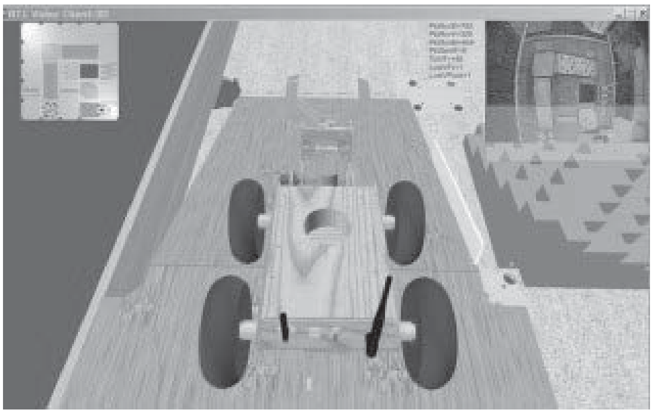

Fig. 10. The cosmonaut's interface during the control of mobile RTC robot

To conduct the sessions of the space experiment “Kontur-2” there was used a Vicon positioning system, which gives very high accuracy of positioning of markers installed on the mobile robot. The data obtained from the Vicon system were used to calculate the force-torque effect on the handle of the joystick, as well as to form a three-dimensional model of the polygon on the astronaut's on-board computer using the Unity program. Fig. 10 shows the appearance of the astronaut's interface consisting of a three-dimensional model of the environment formed in Unity program based on the robot’s position data, as well as the polygon map (a top left corner of the GUI) and camera images (top right corner). In total, during the space experiment, three cameras were used: the first one is an overview camera, which allows to get an image of the whole polygon from the top, the second one is a camera on a mobile robot, and the last one is a camera used to organize videoconferences between developers and a cosmonaut after the control session of the experiment.

All information flows in the space experiment “Kontur-2” are divided into priority and background. Priority flows include robot control commands and robot position data from the Vicon system. These data are transmitted to the ISS using the synchronous part of the S-Band channel. Background streams that include the transfer of video and audio information are transmitted over an asynchronous channel, if possible. As shown above, various algorithms for working with priority traffic were used in our experiment. As it is shown in Fig. 5, the bottleneck between the RTC and the ISS RS is the S-Band channel, whose uplink speed is limited to 256 Kbps. The result of conducting sessions of space experiment “Kontur-2” in 2015 was the necessity to develop new software to manage the quality and volume of the video stream. Fig. 11 shows the appearance of the program that was developed to control the quality and volume of the video stream. This program allows to set the necessary video parameters, such as frame rate, resolution, chrominance, length of UDP packets and also realize the picture-in-picture function, sending one video stream to the ISS instead of two. Also, the program automatically adjusts the video parameters for the given bandwidth of the communication channel, reducing the controlled parameters, which allows reacting quickly to changes in the communication environment to minimize the impact on the priority data stream.

The use of this video server in the sessions of the experiment in 2016 allowed to successfully compensate the negative changes in the characteristics of the telecommunication environment between the RTC and the ISS RS.

The specificity of the space experiment “Kontur-2” in 2016 from the point of view of the used communication channels was the replacement of the physical synchronous communication channel between Weilheim (Germany), where is the receiving and transmitting S-Band antenna, and Oberpfaffenhofen (Germany), where is DLR equipment used in the experiment. Instead of the dedicated physical channel, was used the digital service of SDH E3 over MPLS, which led to a significant increase in the mean of data transfer delay when controlling the mobile RTC robot from the ISS RS. In 2015, RTT between the ISS and RTC during the space experiment varies from 70 to 85 ms. In this case, the dynamics of the delay is explained by the change in distance during the flight of the ISS over the antenna on Earth. RTT between DLR and RTC almost did not change during all the experiments and was about 60 ms. In 2016, the RTT between DLR and RTC did not change, but the total time for data exchange with the ISS increased to 110-140 ms, which is explained by the use of a new logical protocol in the data link. It should be noted that even such a sudden change in the parameters of the communication channel did not interfere with the software of the force-feedback joystick on board the ISS RS to function successfully within the sessions of the “Kontur-2” experiment.

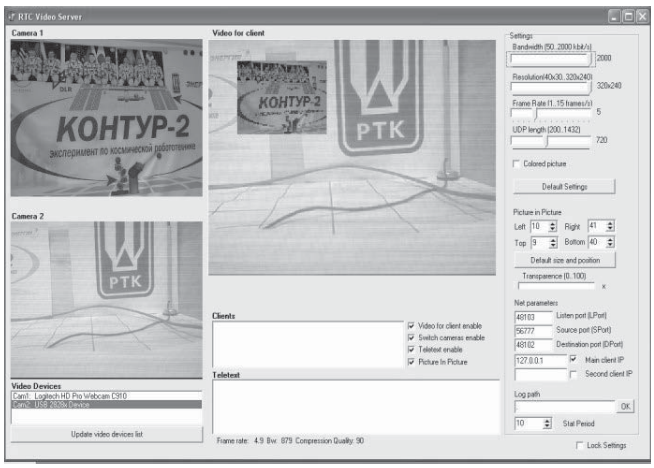

Fig. 11. The video server interface that controls the quality and volume of the video stream

VII. Future Development of the Space Experiment

In future this method of preemptive access management could be used in new joint space experiment “Kontur-3” (new international space experiment) that will be carried out on ground and on-board the ISS, in order to research efficiency and security of robotic operations in space and ground environments, including the configuration of robotic control systems as a part of robotic communication network. Security issues in the remote control of robots are basic and have been reviewed by many specialists, including the authors of the paper [13]-[19]. The joint experiments will focus on the analysis of how well astronauts can operate complex robotic systems based on operation networks with mobility and manipulation capability from within the highly constrained ISS and micro-gravity environment. Multiple human-robot interfaces will be used in combination, while simulating realistic robotic remote operations with round-trip time communication conditions representative of future human planet exploration missions. The structure of data transmission of future experiment is presented in Fig. 12.

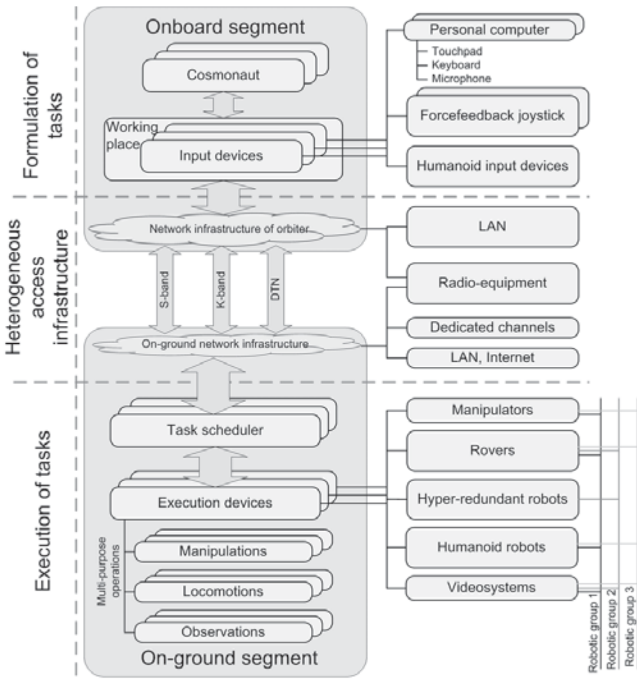

Fig. 12. Data streams in future space experiment "Kontur-3"

For communication experiments, the primary focus will be on the usage of real-time duplex commanding, in combination with Delay Tolerant Network (DTN) approaches. Real-time channel will have low delay (15-20 ms) and high throughput (4 Mb/s), but the connection would be established only when the space station is in the radio-optical range (7-10 min). DTN channels have high delay and low throughput, but function for 24/7.

To enforce access policy and provide information security we had to consider the use of various communication channels in future experiments. That is why the access gateway has two levels of filtering: static and dynamic. Static level allows us to control unchanging policy requirements (such as the use of white lists IP addresses and user authentication process). Dynamic control checks suspicious actions of the permitted users, as well as controls transmitted data, taking into account the used transmission channels and the QoS requirements. Some components of the system have been worked out by our colleagues in the framework of a contract with Ford Motor Company [20]-[22].

The basis of every robotic operation network is high-performance cloud, which is used to decompose the complex task from operator and to monitor its implementation by each robot. So robotics objects within multipurpose operation network would execute the programs and interact without human involvement. However there would be always situations when the robot could not make a decision by its own. In that case the human-operator will have two main opportunities:

1) remote telecontrol through real-time channel;
2) to send new program through DTN.

Heterogeneous cloud platform provides not only remote access for computing resources or applications, but also intelligent services. Using the resources of modern cloud-based engineering centers it is possible to create equivalent social networks that bring together multiple agents to perform coordinated actions, computation, verification of test results based on the use of different materials, virtual prototyping, and data visualization. These problems, from the point of view of the computational algorithms, can be combined into chains, which form a network of operations. Their implementation is provided within a heterogeneous cloud. The components of the platform, based on the OpenStack, include: IaaS cloud class segment, computing infrastructure within the cluster, the specialized high-performance hybrid system based on reconfigurable computing nodes.

Virtualization has changed the approach of deploying, managing, and using enterprise resources by providing new opportunities for consolidation and scalability of computational resources available to applications; however, this leads to the emergence of new threats posed by the complexity and dynamic nature of the process of resources provisioning. These threats can lead to the formation of cascade security violations, which traditional data protection systems are unable to deal with. The existing approaches such as “Scan and Patch” do not work in a cloud environment — network scanners cannot track changes of resources configuration in real time. These approaches do not accurately identify the change in level of risk and take steps to block dynamically emerging threats.

To solve the problem of controlling access in the cloud, it is necessary to continuously monitor resources, and it cannot be achieved without the automatic generation of rules for filtering and firewall log files analysis. Information security management products in a dynamic cloud environment should include mechanisms that provide: total control over processes for deploying virtual machines; proactive scanning the virtual machines for the presence of vulnerabilities and configuration errors; tracking the migration of virtual machines and system configuration to control access to resources. Therefore, within the space experiment "Kontur-2" series of measures are set out to improve information security resources, namely:

- Enhanced Control of virtual machines. Virtual machines as active components of the service are activated in the cloud application random moments, and Administrator cannot activate or deactivate a virtual machine until the security scanner checks the configuration and evaluates the security risks.
- Automatic detection and scanning. Information security services are based on discovery of vulnerabilities in the computing environment. This discovery in turn is based on the current virtual machine configurations and on reports of potential threats that come from trusted sources, such as antivirus update servers.
- Migration of virtual machines. Proactive application migration is an effective method to control security. Each of these data will have its own priority level. The number of priorities could be increased by using the recursive application of prioritization method described above.

VIII. Conclusion

The paper illustrates one of the possible applications of access control and traffic management approach in the tasks of robotic remote control in space experiment “Kontur-2”.

Proposed model considers computer network as the set of VCs, which throughput is easy controlled by proposed classification procedure and algorithm that divides the set of non forbidden VCs in two subsets: non forbidden priority connections and non-forbidden non-priority ones or background connections.

In this paper, we considered in detail the preemptive queueing mechanism, which provides a wide range packet loss probability ratio using flexible randomized push-out algorithm. The most interesting result obtained in congested network allows keeping priority VC throughput near the requested value, which is important for specific space experiment onboard ISS.

Described a practical application example of proposed model in joint space experiment “Kontur-2” onboard ISS where several types of operations are serviced by access gateway in robotic communication network.

Proposed an architecture of access gateway for robotic cloud platform with heterogeneous computing resources that expected to be used in future space experiments onboard ISS.

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