Analysis of the Requirements to Information Exchange Protocol for an All-Optical Onboard Network

Vladislav Kosyanchuk, Valeriy Novikov,
Georgiy Platoshin
FSUE State Scientific Research Institute of Aviation Systems (GosNIIAS), Moscow, Russia
{vvkosyanchuk, vmnovikov, gaplatoshin}@2100.gosniias.ru

Yuriy Sheynin, Valentin Olenev
Saint-Petersburg State University of Aerospace Instrumentation, Saint-Petersburg, Russia
sheynin@aanet.ru, valentin.olenev@guap.ru

***Abstract*—The paper demonstrates relevance of developing onboard intelligent control systems for aircraft systems. The authors provide a definition of intelligent support for the crew of the aircraft system. An onboard network reconfiguration diagram based on WDM network technology is proposed. In addition, authors present the elaborated requirements for information exchange protocols for the future all-optical onboard network technology.**

I. Introduction. Avionics Suite Architecture Based on the Principles of Distributed Modular Electronics

The second-generation integrated modular avionics or distributed modular electronics (DME) is a modern concept of avionics systems architecture involving resource sharing and distributed computing with hardware and software standardization. DME should ensure "release" of computing resources from rigid bond with interface equipment access channels. In this case, the programs for implementing the functions of the dedicated avionics subsystems could be located on any of the computing modules that jointly constitute the onboard distributed information and computing environment (ODICE) of the avionics suite. The real-time ODICEs impose strict requirements on information transmission tools and consist of functional components of the avionics suite (aircraft systems with computing resources and data storage capabilities) and the switching environment, consisting, in its turn, of data transmission channels and network elements (switches, routers, physical channel environment), see Fig. 1. Currently, the onboard communication environment includes interface channels and switching devices [1]:

- redundant routing switches (RS),
- redundant bridges and network controller hubs (NCC).

The routing switches (routers) provide transmission paths for information packages, as well as redundancy and layered protection against errors and loss of messages. The network layout, characteristics and number of routers are specified project-wise after decision making as regards the composition and location of the avionics as a whole.

Bridges and network controller hubs are designed for switching, thus implementing the principle of avionics virtualization. They are actuators that switch the information flows both at the input to the onboard distributed computing environment (ODCE) (from sensors, information systems, receivers of external information channels, etc.) and at its output (information receivers inside the avionics, actuators of various avionics systems, mass information storage devices, etc.). Bridges (gateways) provide buffering and reformatting of information packages at transition between ODICE channels.

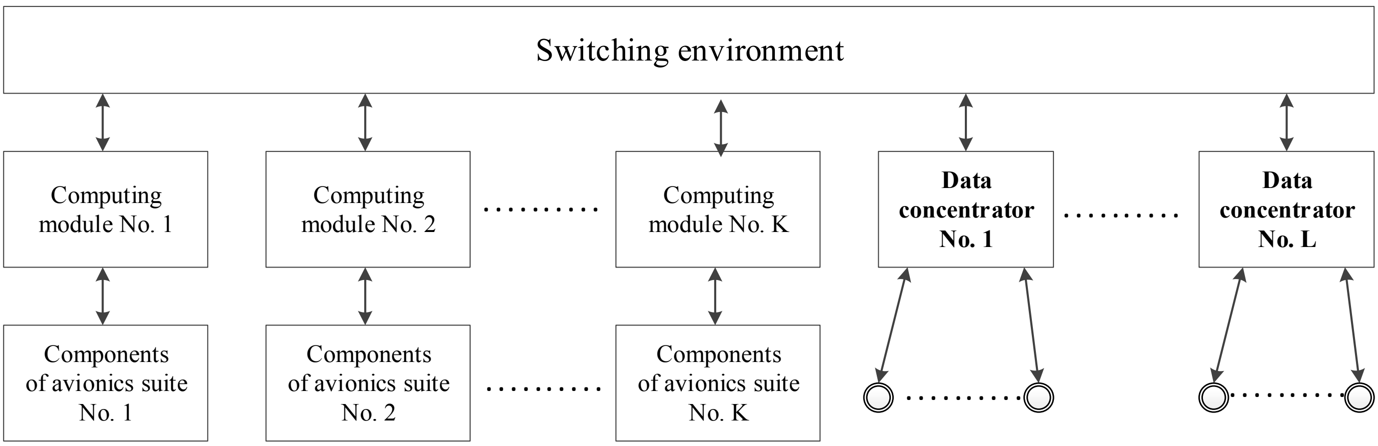

Fig. 1. Architecture of onboard distributed information and computing environment

The DME main requirement is the flexibility and scalability of the structure of advanced avionics suites. All components of individual suites and systems shall be combined by ODCE into the corresponding systems and suites as a result of switching executed by communication tools. Switching options are selected before or during the operation of the avionics suite depending on various factors: the mode, goals and objectives of the item use, the monitoring results of the current state of the avionics suite components and their parts, estimates of the expected functional efficiency of the suite as a whole or its systems, and the degrading level of the available resources.

To provide flexibility, ODICE should support wide scalability in terms of its constituting nodes and modules, access distances from the computing modules to the peripheral nodes, and information exchange rates within the onboard network. For this purpose, the onboard network infrastructure shall be implemented as a unified integrated network environment in which capacity the all-optical onboard network is proposed.

II. All-optical onboard network as DME architecture environment.

The all-optical onboard network (AOON) represents a class of networks in which switching, multiplexing and retransmission functions are solely enabled by optical and not electronic functions. All-optical networks claim to be the dominating network technology as the fiber-optic transmission lines (FOTLs) have a number of advantages over the wired (copper) communication systems [2,3]. Organizing the AOON-based avionics DME has the following advantages:

- any optical network subscriber can access the resources of any other subscriber;
- all-optical onboard networks enable the transition from time-division sequential multiplexing of the information that is being transmitted (requiring a constant increase in the transmission rate) to parallel spectral multiplexing (not requiring an increase in the data transmission rate);
- no delays and conflicts in the real-time network;
- possibility of unifying the exchange protocol;
- simplified method for solving reconfiguration tasks in case of failures;
- implementation of the DSM-based information environment creates a single system image available to all programs of the aircraft avionics suite. Interface nodes degenerate into memory space.

The technical result achieved through AOON implementation is real-time information exchange in the onboard network with guaranteed message delivery, implementation of the avionics reconfiguration procedure in case of failures and, as a result, improvement in flight reliability and safety parameters.

The traditional telecommunication technologies ensure only one signal transmission via a single optical fiber. The essence of wavelength-division multiplexing (WDM) is the possibility to organize transmission of plural separated signals via a single fiber, and hence to multiply the communication line throughput - implementing WDM/multiplexing of plural signals transmitted via one optical fiber - WDM technology.

Current WMDs can be divided into three groups:

- simple WDM systems are systems with the number of channels not exceeding 16;
- dense WDM systems are DWDM systems with the number of channels not exceeding 80;
- high dense WDM systems are HDWDM systems with the number of channels up to 320.

An all-optical onboard network (AOON) is based on the principle of the network architecture organization, when each end node of the network is assigned a specific group of wavelengths (λ-channel) used by the node for transmission. Signals from all remote nodes are collected in an optical star coupler/multiplexer, where they are mixed and distributed across the output poles into fibers going back to the remote nodes. Ideally, each node can receive a multiplex signal represented by all wavelengths, i.e. information from all nodes, via all channels. The requirements for the implementation of the DME of avionics suite based on all-optical onboard network (see Fig. 2) are as follows:

- the avionics architecture is divided into many components;
- each system includes a number of onboard computers:
- each onboard computer executes a number of software applications that are data source (software application source) for other applications, in other components of the avionics suite, or/and executes software applications that are consumers of information (software application receiver) from other components of the avionics suite;
- each software application data source is assigned a separate value of wavelength λ^p in the optical interface, this will correspond to a dedicated channel for data transmission from this software application source (λ channel);
- several λ-channels can come from one computing system (depending on the required level of integration and technical capabilities of the optical network);
- at the computing system output occurs local multiplexing of λ-channels and generation of one optical summation channel for the given system, i.e. λ^S-channel;
- all λ^S-channels from all systems come to a common optical multiplexer where general multiplexing of all λ^S-channels from all systems occurs, and common/global output spectrally multiplexed channel is produced, i.e. λ^{OUT}-channel.
- λ^{OUT} channel goes back to all onboard components, to all onboard systems where demultiplexing, separation of all or some λ-channels are performed, with their subsequent conversion and transmission for operation to software application receiver.

Organizing the AOON-based avionics DME has the following advantages:

- any optical network subscriber can access the resources of any other subscriber;

- all-optical onboard networks enable the transition from time-division sequential multiplexing of the information that is being transmitted (requiring a constant increase in the transmission rate) to parallel spectral multiplexing (not requiring an increase in the data transmission rate);
- no delays and conflicts in the real-time network
- possibility of unifying the exchange protocol;
- simplified method for solving reconfiguration tasks in case of failures;

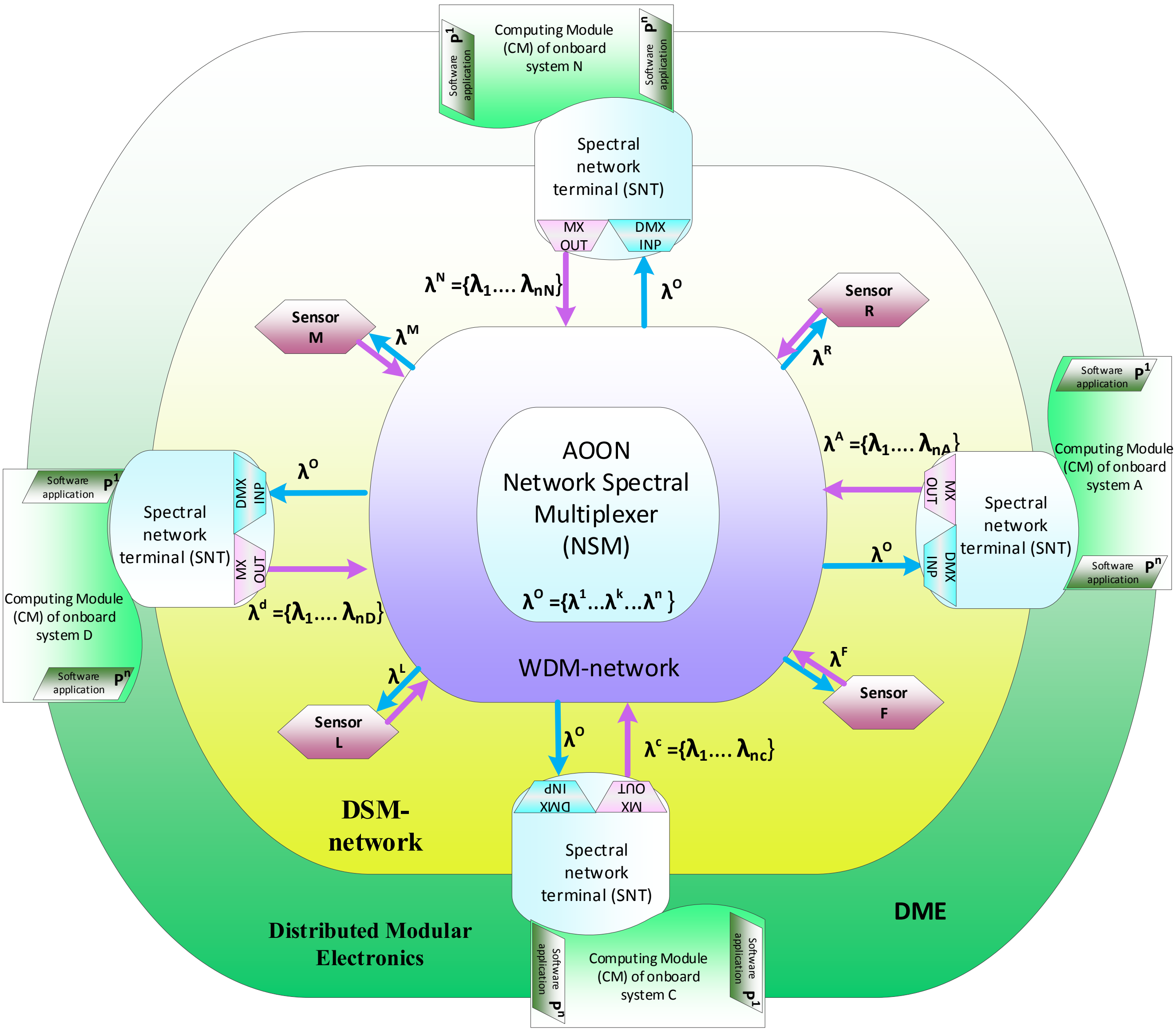

Fig. 2. Architecture of DME avionics suite based on all-optical onboard network

The technical result achieved during the AOON implementation is the real time information exchange in the onboard network with guaranteed message delivery [4].

Such an approach differs from the existing solutions that are used for the optical onboard networks of the airplanes, so the implementation of AOON would be a new step for the development of a new technology.

III. Implementation of Intelligent Assistance to the Crew on the Basis of the All-Optical Onboard Network

The intention of the AOON implementation on aircraft is its use to solve the most complex tasks of aircraft control, namely, the crew intelligent assistance (CIA). The purpose of the development and implementation of the intelligent assistance tools onboard an aircraft is to achieve the following objectives [4]:

- Intelligent assistance (IA) carried out at all stages of the flight.
- IA to determine in-range and control zones;
- crew IA for counteracting air and ground threats;
- crew IA in the event of major failures;
- crew IA when performing complex aerobatics.

The intelligent assistance provided to the crew is regarded as the process performing automatic analysis of the current tactical situation, capabilities and technical condition of aircraft systems, optimal communication to the crew about external and internal conditions, and adaptive automatic or automated avionics control in the course of performing the flight tasks. [5].

A special feature of the crew IA system development is the objective of designing the real time intelligent systems focused on open and dynamic subject areas. Such systems are based on models capable of adaptation, modification and learning, oriented towards specifics of the given subject area and the corresponding type of uncertainty (see Fig. 3). When implementing the IA system, the following shall be considered:

- the need to obtain a solution in the conditions of time constraints determined by the actual controlled process for aircraft systems;
- the need to consider the time factor in the description of the problem situation and in during the solution search;
- the impossibility to obtain complete objective information necessary for the decision making, and, therefore, the need to use a subjective, expert assessment of the situation;
- multivariate searching, the need to use methods of reasonable conclusion and involvement of a human in the active search process, i.e. the inability to fully automate the process of technological situation control.

One of the intelligent assistance tasks being realized at all flight stages is developing solutions for the cases of avionics failure by reconfiguring the avionics suite. Reconfiguration is the process of changing the composition and structure of the avionics suite aimed at maintaining the system's real-time performance or adapting the system to the changed conditions [6].

The reconfiguration object is the onboard distributed computing environment (ODCE) comprising the single-type computing modules (CMs) integrated in the onboard network. ODCE includes K computing modules and L data hubs, all of which have access to the onboard network (ON). The avionics suite reconfiguration logic consists of the three stages:

- monitoring the status of avionics systems;
- global arbitration and creating a new image of the avionics suite hardware, software and network configuration;
- implementation of the avionics suite reconfiguration program.

For implementation of the first and second stages, the main requirement is to arrange information interface between onboard network subscribers according to the "*one-to-all, all-to-one*" principle. Only the all-optical onboard network considered above is fully compatible with these requirements.

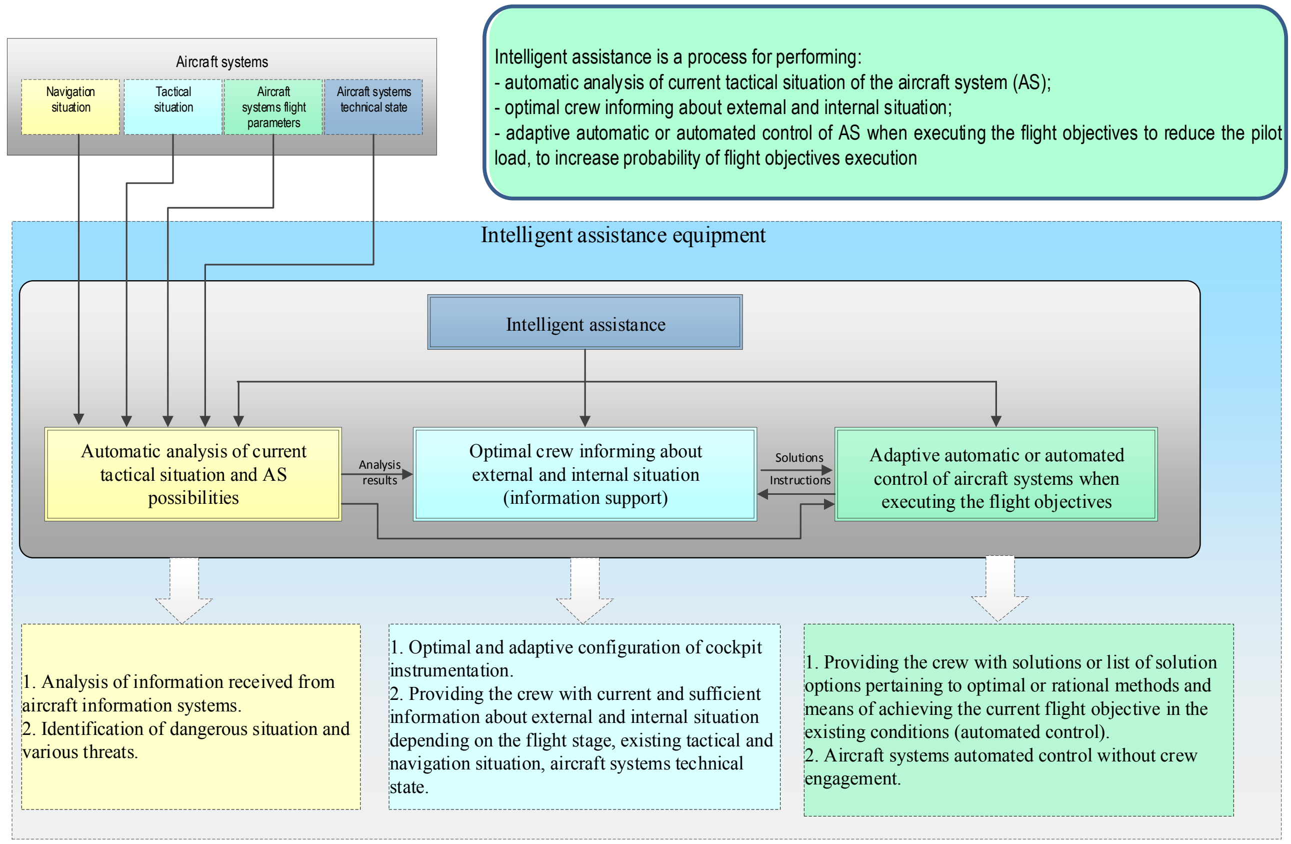

Fig. 3. Functional composition of crew intelligent assistance

IV. Analysis of the Requirements for the AOON Information Exchange Protocol

Modern aircraft onboard networks do not provide solutions for modern tasks with intelligent assistance, since existing networks are multi-level, containing a large number of different protocols [7]. Performance of tasks in the aircraft's onboard network is determined by real-time mode, hence the implementation of multilevel complex protocols is not always effective. Therefore, the developed AOON protocol shall be simple and focused on maximum response time.

The new protocol for AOON shall comply with the data link, network and transport layer of the OSI model [8] and is intended to provide appropriate services for optical onboard aircraft networks. The protocol shall determine the information and logical interaction, regulate the formats of the transmitted data and the rules for message transmission between the AOON subscribers.

In accordance with the concept proposed at the AOON physical layer it is necessary to develop a new protocol as part of the ongoing work, instead of using one of the existing protocols. Ideally, it is desirable that the optical network is protocol-invariant, i.e. so that the principles at the basis of AOON could be used with other protocols as well, such as AFDX, SpaceFibre [9], etc. In this case, the protocol itself shall be designed for operation in the optical network, including with network speed control, which is required for AOON reconfiguration [10].

To carry out the reconfiguration or other network settings, one needs a special network operation mode, during which verification, setting and configuration will be carried out. This shall be provided upon AOON switching-on, as well as in emergency cases and during routine inspections. To operate in this mode, as well as in some other cases, it is necessary to provide a mechanism or a separate protocol for remote access to the device memory, for example, the RMAP protocol [11] used for setting and reconfiguring in SpaceWire onboard networks.

Based on Fig. 2, the protocol will not have a network layer, since the proposed AOON architecture does not require package routing, they are broadcasted to all AOON subscribers, where they are filtered out by the network adapters of the subscribers.

The developed AOON architecture, where each data stream is uniquely assigned to one wavelength value in the optical channel, will allow data exchange between network terminals, at a logical level, as per point-to-point principle.

As part of the data exchange at the physical layer, bit stream encoding shall be provided. However, since the encoding and decoding process can take a long time and delay the data exchange, it is necessary to choose which bit stream encoding will be optimal. From all the possible options, the best solution appears to be 8b10b encoding, which is used in various high-speed serial data transmission protocols including optical channels.

The next requirement for the developed protocol is the need to introduce restrictions of the data transmission rate. Very high rates are not yet necessary for operation in the aircraft onboard network. In the protocol it is enough to be able to switch between several specified rates. For example, using a standard range of rates 1.25, 2.5, 3.125, 4, 6.25, 10 Gbps, the minimum possible data transmission rate is 10 Kbps, and the maximum rate is 10 Gbps. If it is necessary to transmit packages at higher rate than it is physically possible with one optical channel at single wavelength, then it is possible to use paralleling of information stream transmission over several logical optical channels on several $\lambda i - \lambda i + n$, using the inverse multiplexing method, multilane, at symbol, frame or package level.

In order to implement such mechanisms as stream monitoring or guaranteed delivery in the protocols of the data link and transport layers, implementation of duplex data transmission channels is required. For such implementation, each λ-channel should have its own return channel with separate λ. This approach will reduce the number of potentially operable channels by 2 times. To avoid that, one or more channels can be implemented to enable only the flow of service information. When organizing control of the information transmitted via the AOON network one can also use the feature of broadcasting information transfer, i.e. the source node also receives information transmitted by itself, and if its network adapter does not filter out and permits passage of the package transmitted by the source, the source can compare the package transmitted by the source with the package received from the network.

So, AOON will have three main groups of λ-channels:

- Information channels designed to transmit information packages;
- Reconfiguration channels designed for setting;
- Service channels for service information transmission, such as flow control tokens (FCTs), acknowledgment packages, etc.

Apart from the spectral multiplexing in AOON it is necessary to provide time multiplexing [10]. In this case, several time slots are provided for each λ-channel to ensure exchange, so one channel can be used for several applications. Such mechanism is called the quality of the “Planning” service, and it is implemented in such protocols of spacecraft onboard networks as SpaceWire-D [12] and STP-ISS [13]. If this approach is used, then a single schedule is created for each λ-channel, where for each application working through this channel one or more time slots are allocated for the information exchange.

Based on the specifics of network exchange in AOON and aircraft onboard networks, the new data transmission protocol in AOON shall support work with 5 main types of data:

- Control commands (highest priority);
- Urgent messages (high priority);
- General messages (medium priority);
- Video data (low priority);
- Empty packages NULL (lowest priority).

The protocol shall ensure continuous data transmission via the channels in order to ensure the continuous operation of the laser for transmission via the optical channel. It is necessary to provide empty packages NULL so that the laser will have no ability to turn off; otherwise, it will require considerable time to turn on and heat up. However, the laser has limited operation time; therefore, for some types of data exchange, it is possible to have a mode of data sending without NULL packages, for example if data via specific optical channel are rarely transmitted. Switching between the two exchange modes will be possible at the stage of protocol reconfiguration.

The size of incoming data will be from 10 Kb to 1 Mb, including additional accompanying information and secondary headers. Therefore, a mechanism for splitting the packages into segments is required. Nevertheless, packages segmentation is supposed to be carried out using application-level protocol tools and the applications themselves, since this mechanism is difficult to implement and costly in terms of the size of the area occupied on the chip.

The AOON protocol shall provide for the service qualities “Guaranteed Data Delivery” and “Non-Guaranteed Data Delivery”. The guarantee is needed when delivering the control commands, urgent and common packages. Non-guaranteed delivery may be necessary when transmitting stream traffic (video data).

The preliminary architecture of the AOON protocols stack is shown in Fig. 4.

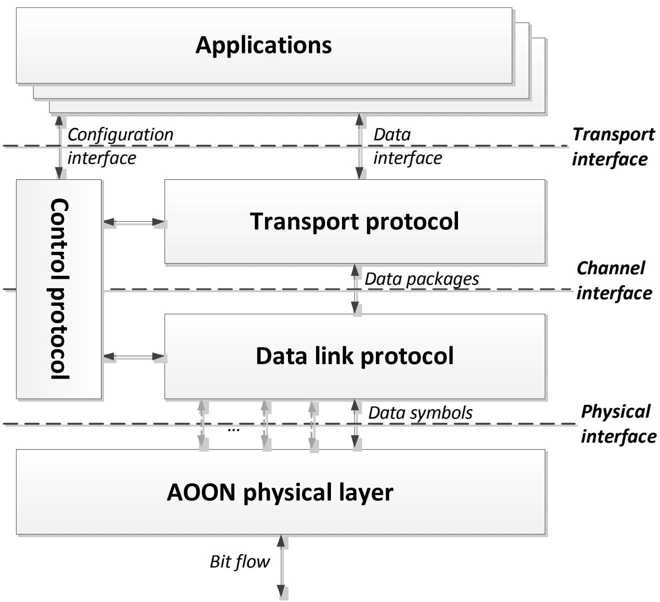

Fig. 4. Preliminary architecture of AOON protocols stack

Meeting the above requirements will allow to create such protocol or stack of protocols that enable efficient use of AOON resources and provide maximum functionality and availability of the network for potential users. Providing various data transmission rates, flexibility of protocol configuration and various service qualities will increase the competitiveness and efficiency of aircraft onboard equipment.

V. CONCLUSION

Ensuing from the aforementioned, the proposed real-time information exchange system is free from a number of disadvantages. Firstly, the switch is excluded from the system, no need in priorities setting between channels. Secondly, each software application has its own group of dedicated channels that guarantee real-time data exchange. Moreover, ensured implementation of the avionics suite reconfiguration in case of failures.

Current paper described the first stage of a project. The new approach for the optical network implementation was chosen and requirements for the AOON and protocol stack was elaborated. The next step of the work is implementation of AOON protocols stack specifications, AOON simulation models and get the first experimental results by modeling.

REFERENCES

[1] G.A. Platoshin, N.I. Selvesyuk, V.M. Novikov “*Prospects for designing a uniform onboard multi-level interface for building an onboard information and computing network*”, Actual problems and perspective directions of development of aircraft equipment systems: proceedings of the Third All-Russian Scientific and Technical Conference “Academic Zhukovsky Readings”, Voronezh, 2015.

[2] V.M. Novikov “*The concept of using all-optical onboard networks for solving the tasks of dynamic reconfiguration of the DME-based onboard information and computing environment*”, Proceedings of the Fifth All-Russian Scientific-Practical Conference, Voronezh: Air Forces Academy, 2017.

[3] V.M. Novikov “*Development of methods for designing an avionics suite architecture on the basis of a uniform optical environment”,* Proceedings of the International Scientific Conference “Mathematical modeling and information technologies in engineering and business applications”, Voronezh: Voronezh State University, 2018. pp. 237–254.

[4] Patent for invention No. 2694137 "*Real-time information transmission system based on all-optical wavelength division multiplexed onboard real-time network*", 2018.

[5] V.M. Novikov, S.V. Privalov, E.V. Vakhrushev “*Approaches to the development and implementation of onboard intelligent control systems for aircraft systems*”. Proceedings of the second All-Russian scientific and practical conference. Voronezh: Air Forces Academy, 2015. pp. 207–212.

[6] A.A. Tarasov “*Functional reconfiguration of fault-tolerant systems*”, Moscow: Logos, 2012.

[7] Sheynin Yu. E., Novikov V. M., Platoshin G. A. “*Features of SpaceWire interface application in avionics suites*”, Proceedings of GosNIIAS. Series: Avionics Issues. Publisher: State Research Institute of Aviation Systems (Moscow), Volume: 7 (40), 2018, pp. 41–69.

[8] Tanenbaum, A. S. Computer Networks, Fifth Edition; Prentice Hall, 2011.

[9] ESA (European Space Agency), “Standard ECSS-E-ST-50-11C, Space engineering. SpaceFibre - Very high-speed serial link”, European cooperation for space standardization / ESA. Noordwijk: ESA Publications Division ESTEC, 2019.

[10] V.M. Novikov “*Solving the problems of intelligent assistance regarding the avionics suite reconfiguration in case of failures. current avionics research problems: theory, service, developments*”. Proceedings of VI International Scientific and Practical Conference "Aviator", Voronezh. 2019, pp. 189–192.

[11] ESA. “Standard ECSS-E-ST-50-52C, SpaceWire — Remote memory access protocol”. Noordwijk: Publications Division ESTEC, February 5, 2010.

[12] S. Parkes, A. Ferrer-Florit, “*SpaceWire-D – Deterministic Control and Data Delivery Over SpaceWire Networks, Draft B*”. April 2010.

[13] Y. Sheynin, V. Olenev, I. Lavrovskaya, I. Korobkov, D. Dymov “*STP-ISS Transport Protocol for Spacecraft Onboard Networks*”, Proceedings of 6th International SpaceWire Conference 2014 Program; Greece, Athens, 2014. pp. 26-3.