D 1.1 Consolidated set of Requirements for SpaceWire-RT

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1 Introduction

Every next generation of the space technology differs from the previous ones mainly because of the latest progress and results of the fundamental science, industrial technologies and equipment, used during the period of its creation.

Current period is characterized by the quick growth of a number of functional subsystems with the data exchange network characteristics in the structure of the on-board equipment complexes of space vehicles. The requirements to the advanced control systems of space vehicles define the growing need in the effective, reliable and high-speed digital network technology. Control systems of space vehicles, presupposing the usage of on-board network systems for data exchange, become more information-roomy, and the changing architecture of the on-board equipment complexes requires the greater data levels, transmitted between the subsystems. Video transmission and processing toughen the requirements to the characteristics of the data exchange on-board systems, and various functional applications, implemented in the on-board equipment complexes of space vehicles, assist the toughening of requirements to the computer aids, performing the processing of current data.

Data streams, formed by the growing number of complex functional subsystems of the perspective spacecraft on-board equipment complexes, in many cases considerably exceed the capabilities of the traditional on-board interfaces, MIL-STD-1553 particularly. During the period of time, when the multiply tested standard network technologies are widely called-for in the modern spacecraft on-board equipment complexes, the perspective SpaceWire-SpaceFibre interfaces offer the new level of functional capabilities.

Many of the newest information technologies, including SpaceWire, are based on the usage of the physical environment network switching architecture and become the variations or improvements of the main "point-to-point" topology.

Mainly this paradigm became the basis of the network architecture with the commutative environment (switched-fabric-interconnect). This technology provides the considerable growth of the organizational capabilities of the avionics intersystem connections and intersystem connections of the on-board computing facilities. The intersystem connections, organized optimally, and the dynamically created virtual connection channels with the shareable system resources of the transmission facilities mostly define the character of the on-board computing facilities, as they use new highly intellectual matrix commutators and highly-reliable, fail-safe communication channels.

This report shows the results of the WP1 work package "Spacecraft avionics and payload use cases”, completed within the scope of the SpaceWire-RT program with the following objectives:

- submit a combined set of requirements and scenarios of the SpaceWire-RT technology use, taking into consideration the requirements of the main manufacturers of space vehicles and equipment of the European Union, the Russian Federation and other countries.
- determine and validate the requirements to the SpaceWire-RT standard, taking into account the requirements to the effective load and space-borne radio-electronic equipment of a space vehicle.

In the course of execution of work package WP1 the executors:

- analyzed the current standards of the SpaceWire technology,
- examined the tasks and objectives of the proposed SpaceWire-RT research program,
- determined the action plan concerning the introduction of the SpaceWire technology into the space industry of the Russian Federation,
- organized the execution of the first action items of this plan:
- dissemination of information about the SpaceWire technology among the enterprises of the space industry of the Russian Federation,
- carrying out discussions concerning the advantages and disadvantages of the SpaceWire technology on various levels with different organizations,
- performed interviews of the space industry enterprises about the requirements to the proposed SpaceWire-RT technology and scenarios of its usage in the space industry of the European Union and Russian Federation (Section 6 of the Report),
- carried out an analysis and generalization of answers and development of a combined set of requirements and scenarios of the SpaceWire-RT technology use on their basis, which will take into consideration the requirements of the main manufacturers of space vehicles and equipment of the European Union and the Russian Federation (Section 6 of the Report).

2 Analysis of existing SpaceWire technology

The existing set of SpaceWire standards provides the possibility to create space-borne equipment for various applications.

This Section gives a general analysis of strong and weak sides of the existing SpaceWire standard, possibilities to use its strong sides to diminish the weak ones from the viewpoint of constructional realization of the equipment using the SpaceWire interface. From the constructional viewpoint any equipment is realized in the form of board, block or several blocks. Respectively, the interface can provide intraboard, board-to-board and interblock connections.

The block is characterized by availability of the frame, providing protection from external exposures. Table 1 gives the simplified analysis of the properties of the existing SpaceWire interface from the viewpoint of its usage for various types of interconnections: intraboard, board-to-board and interblock. This table shows directions in which the existing SpaceWire technology should be developed in order to use it in advanced space vehicles.

Table 1

N	Characteristics	Estimation for various types of interconnections		
		intraboard	board-to-board	interblock
1	Link – “point-to-point” duplex channel	Random network topology	Random network topology	Random network topology
2	Smooth rate transfer scale 2-400 Mbits/s	In most cases it is sufficient. In the long term it should be increased.	In most cases it is sufficient. In the long term it should be increased.	Sometimes data transfer rate must be equal to 1-20 Gbits/s.
3	Transmission range up to 10m	Sufficient for board	Sufficient for connections inside block	For connections between blocks the distance often makes up from 30 to 100m.
4	Physical medium 4 diff. pairs with characteristic impedance 100 Ohm	Easily realized on board	Easily realized on base board	It is desirable for cable to have less conductors and smaller weight.
5	Immunity resistance to common-mode interference up to 1V	Interference resistance sufficient for board	Interference resistance sufficient for connections between boards in block	Interference resistance isn’t enough for connections between blocks. (it is desirable up to 10V)
6	Low power consumption	Very important for board	Very important for block	For realization of galvanic separation and higher data transfer rate the energy consumption can be increased
7	Simple and compact realization in VLSIC (very large scale integrated circuit)	Important for board	Important for block	For realization of galvanic separation and higher data transfer rate the energy consumption can be increased
8	Support of common system time	Very important function on any level	Very important function on any level	Very important function on any level
9	Availability of interrupt distribution system	Very important function on	Very important function on	Very important function on any level

N	Characteristics	Estimation for various types of interconnections		
		intraboard	board-to-board	interblock
		any level	any level	
10	Galvanic isolation is absent	Galvanic isolation isn't required on board	Galvanic isolation inside block isn't required, as a rule	Galvanic isolation between blocks is a very important property
11	Capability of broadcasting and multicasting	Absent, but necessary for fault tolerance provision	Absent, but necessary for fault tolerance provision	Absent, but necessary for fault tolerance provision
12	Reserve for increase in performance	Small, must be increased	Small, must be increased	Small, must be increased
13	Reserve in decrease of latency time for message delivery	Absent, must be increased	Absent, must be increased	Absent, must be increased
14	Full responsibility of network for data transmission	Absent, but is very desirable	Absent, but is very desirable	Absent, but is very desirable
15	Resources necessary for provision of dynamic redundancy and automatic controllable network degradation	Considerable, decrease of resources usage is required	Considerable, decrease of resources usage is required	Considerable, decrease of resources usage is required
16	Sufficiency of mechanisms of out-of-band signalling for advanced systems	Not enough, more powerful means are required	Not enough, more powerful means are required	Not enough, more powerful means are required

3 Use cases

3.1 Scientific satellites (Earth observers)

The use case describes the potential use of SpW-RT in satellites.

Scientific satellites often have similar network architectures. One of the main differences between the satellites itself is the number of instruments which are connected to. Data rates can also be different depending on the connected instruments. SAR (Synthetic Aperture Radar) instruments or optical instruments have often a request for high data rates due to the nature of the generated data. Beside the high data rate instruments there are also instruments which require a moderate or even low data rate.

Scientific satellites incorporate a Data Handling System (DHS) and Payload instruments. The communication network is based on a SpaceWire network. The routing inside the SpaceWire network can be partitioned into three parts:

- a SpaceWire network connecting the instruments, OBC (OnBoard Computer) and solid state mass memory (SSMM) which handles telecommand (TC), telemetry (TM) and science data transfer;
- links between the on-board memory and the OBC Telemetry Formatter (TF);
- point-to-point links between the OBC and the RIU (Remote Interface Unit).

Payload instruments are connected by SpaceWire interfaces to the solid state mass memory. Each payload instrument has a dedicated SpaceWire interface. The TM/TC packet routing and multiplexing is centralized within the SSMM. An adequate SpaceWire acquisition priority scheme is implemented for payload instrument data acquisition to avoid long interruption of an on-going TM packet transfer. This kind of approach will give full flexibility to the payload instruments and allows TM packet transfer to the SSMM without any higher level handshake protocol.

The OBC Processor Module is connected to the SSMM via SpaceWire interfaces. All telecommand and telemetry data packet transfer to and from the SSMM is done via this SpaceWire interface.

The OBC TF is connected to the SSMM via SpaceWire interfaces. All data for downlinking from the SSMM can be done via this SpaceWire interface.

The OBC Processor Module is connected to the RIU via SpaceWire interface. Communication is based on protocols. Currently all communication is initiated by the OBC. This may change in the future.

Figure 1 shows a typical SpaceWire network structure of a scientific satellite.

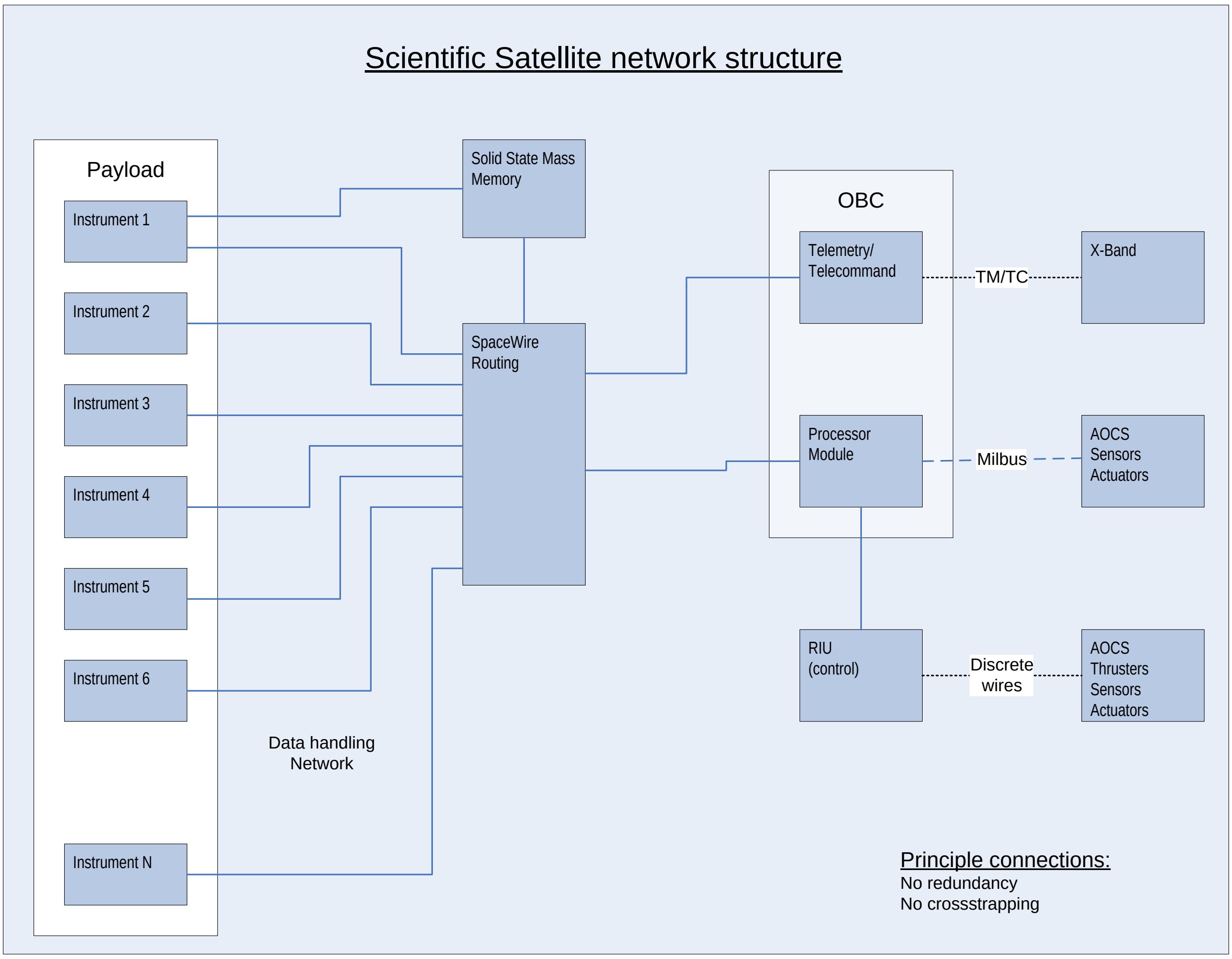

Figure 1 – network structure of a scientific satellite

In a scientific satellite exists several different functions which can be handled by a SpaceWire network:

- Data-handling network connecting instruments with memory units
- Control bus for commands from control module to instruments and other equipment of the spacecraft
- Telemetry bus for collecting housekeeping information
- Computer bus for data exchange between computer modules

Scientific satellites include several different types of networks. SpaceWire-RT aims to incorporate as much as possible of these different functions into one network: SpaceWire.

There are additional functions which can be realized within the SpaceWire network or outside of it depending e.g. on the required precision of these functions.

- Time-synchronization bus for space-borne clock synchronization

If very high precision or accuracy is required these functions are realized as discrete signals.

- Side-band signal for signaling and control in hard real time

Satellites can be split in the avionics part and the payload part. From operational part of view the avionics part is the most critical. If failures occur in the avionics part which could not be solved, the probability to lose the complete satellite is high. If similar failures occur in the payload part an instrument may not work correctly or may be lost, but the satellite as such is still operational. From these aspects the command and control inside a satellite is often realized with Milbus 1553. The requirement for SpW-RT is to provide reliability/determinism comparable to the Milbus 1553 for satellite avionics.

3.1.1 Determinism

In current satellite architectures the command and control function is often implemented as Milbus (1553). An advantage of Milbus 1553 is that the handling scheme is very deterministic, because it is a bus topology with only one bus controller and several remote terminals. The bus controller manages the complete traffic going over the Milbus. To enable the implementation of the command and control function in a SpaceWire network the traffic over the SpaceWire network must be deterministic. Deterministic in this case means that mechanism must exist which guarantees that packets arrive in a certain time at the receiving node. This determinism mechanism has to work over the complete SpW network.

In parallel, determinism has to guarantee that instruments, on-board memory, onboard processor, and telecommand/telemetry modules are able to deliver their data in time without losing any.

3.1.2 Length

The length of SpaceWire connections inside a satellite can have a wide range. There are SpW connections which are very short and other which can be rather long. Connections to instruments via a cable can easily reach dimensions of meters. Other SpW connections for example inside a box can even be below one meter. Of course these differences in length have to be handled with the appropriated interface level like single-ended or LVDS.

3.1.3 Instruments

There are several different kinds of instruments in a scientific satellite. On one end there are non-intelligent instruments like sensors and on the other end there instruments with processors for any kind of processing. All these instruments are connected via the same SpaceWire network.

The non-intelligent instruments are configured and controlled by the Onboard processor. For the configuration and the controlling for the non-intelligent instruments a protocol is required which runs on top of SpaceWire.

The intelligent instruments contain a local processor to control and operate the instrument. They can exchange status with the onboard processor via SpaceWire. The (scientific) data are transferred to the on-board memory via the SpaceWire network.

3.1.4 RIU (Remote Interface Unit)

The Remote Interface Unit is directly connected to the onboard processor via SpaceWire. The data rate of this SpaceWire link is in the range of tens of Mbit which means moderate data rate.

Inside the RIU a controller configures and controls the connected sensors and actuators. The sensor and actuators are linked to the controller via discrete wires. The RIU collects housekeeping data and transmits the housekeeping data via SpaceWire to the onboard processor.

3.1.5 Solid State Mass Memory

The solid state mass memory stores all kind of data, telemetry and telecommand data as well as scientific data. The SSMM incorporates more than one SpaceWire interface. In the case that in the satellite is an instrument which generates a high amount of data, this instrument can be connected directly to the on-board memory without going through the routing elements.

The receiving data rate at the on-board memory depends on the data rate of the connected instruments. In general is the accumulated receiving (incoming) data rate much higher than the transmitting (outgoing) data rate at the on-board memory. The reason for this is that there are several instruments which want to store their data in the on-board memory and only a few destinations where the stored data can go.

The on-board memory includes a memory controller to manage the storage of all the different kind of packets.

3.1.6 Telecommand/Telemetry

The telecommand/telemetry module is connected via a telecommand/telemetry interface to the antenna. The uplink/downlink rate of the antenna defines mainly the required SpW data rate of the telecommand/telemetry module and is in a moderate range (around ten Mbit/s).

3.1.7 Onboard Processor

The onboard processor communicates via a point-to-point SpaceWire link with the Remote Interface Unit. The onboard processor has also one or more SpW interfaces into the routing network. This SpW interface is used to command and monitor the payload instruments connected to the SpW network. The SpaceWire routing function is mostly implemented by SpaceWire Router devices. These SpW-routers contain routing-tables for logical addressing and configuration registers. A further task of the onboard processor is to setup probably the routing-tables and the router configuration registers.

3.1.8 Routing

The SpaceWire routing is implemented by dedicated SpaceWire Router devices and SpaceWire routing function within other SpaceWire devices. As there is no local processor within the SpaceWire router device the complete configuration and setup is done by another device, like onboard processor, via SpaceWire interface. The necessary data rates of the different SpaceWire interfaces are setup by the onboard processor. The data rates itself are depending on the instrument, on-board memory, etc. connected to these interfaces.

3.2 Piloted spacecraft

A distinctive feature of this case is the maximum degree of reliability required for life of the crew. Other requirements, such as the use of galvanic isolation for example, are largely the consequences of this basic requirement.

Spacecraft network structure is shown on Figure 2. Spacecraft consists of two main parts: Landing capsule (LC) and Engine section (ES).

Each part is controlled by its own onboard computer (OBC). Landing capsule and Engine section have two-level network structure – upper level is supported by OBC and Main router, lower level of network is supported by local routers located in the respective areas of control. LC Main Router and ES Main Router are connected by redundant SpaceWire/SpaceFibre links. They are separated during the descent procedure, and then each part should provide an independent performance.

Landing capsule contains Crew area and several equipment areas. Respectively Engine section contains Engine Area and few equipment areas.

3.2.1 Onboard computers

Redundant Landing capsule onboard computer includes four computing modules, connected by point-to-point SpaceWire computer bus links. Each computer module has separate connection to other computing modules. Computer bus links shall provide minimal latency down to 100 ns to ensure synchronous operation of modules and high data rate for exchange between them.

Computer modules are also connected to Main Router by redundant SpaceWire links. These links are intended for all kinds of data exchanges including Control, Telemetry, Time-synchronization and Interrupt transactions.

As crew life depends on operation of the system, the highest level of reliability is needed. It results in such requirements as validity, acknowledgements, fault detection and identification, failure and fault tolerance of network, multi-path transmission.

As redundant modules shall receive the same information multi-cast data transfer is needed.
Engine section onboard computer is similar to LC onboard computer, but consists of only two computing modules instead of four.

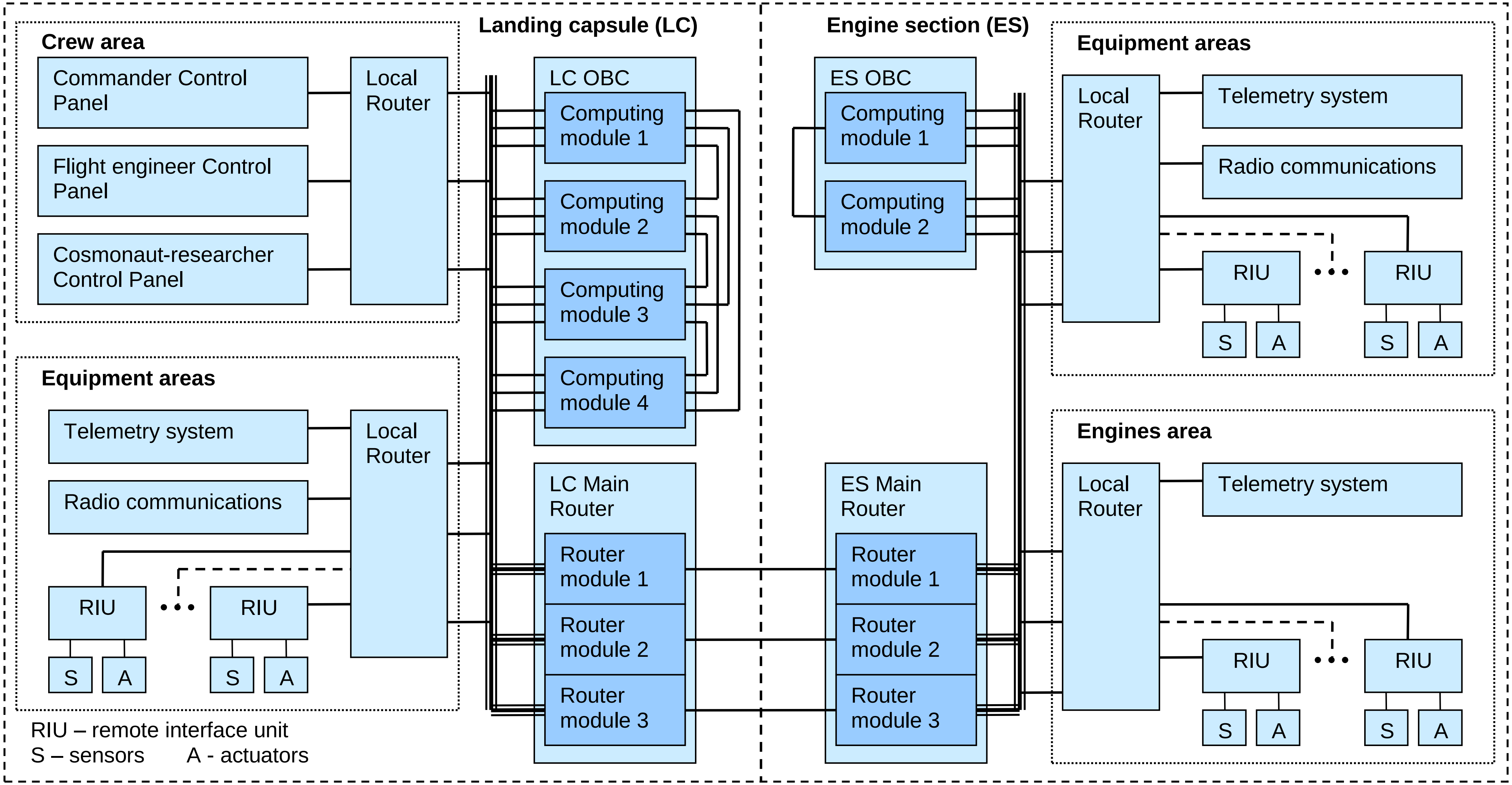

Figure 2 – Piloted Spacecraft network structure

3.2.2 Main routers

LC main router and ES main router are of the same type. Each of them consists of three routing modules.

LC network and ES network are connected by redundant SpaceWire/SpaceFibre links.

Galvanic isolation is needed for this link as it connects two large systems, which shall continue operation after separation.

It also requires all measures to ensure the reliability of the above for on-board computers.

Onboard computers and local routers are connected to main routers by redundant SpaceWire links. This allows system operation after two failures.

3.2.3 Local routers

The landing capsule and engine section contain a number of instrumental zones, each of which is served by its local redundant router (local router redundancy is not shown on Figure 2).

These zones may be spatially separated by large distances, which also require galvanic isolation.

3.2.4 Control panels

Crew area contains three control panels for commander, flight engineer and cosmonaut-researcher.

Commander and flight engineer control panels are similar and are intended for:

- systems and units management;
- manual correction in emergency situations;
- transition to manual control systems to rescue the crew in emergency situations;
- issuing critical commands;
- audio and video communication;
- traffic control, orientation and descent;
- control of individual life support;
- request command and telemetry data;
- onboard documentation support;
- event logging.

Cosmonaut-researcher control panel is intended for:

- reporting status information of on-board systems;
- audio and video communication;
- control means of individual life support;
- reception of digital video and audio streams;
- cartographic mapping and navigation data;
- onboard documentation support;
- event logging.

Control panels require reliable control of onboard systems, as well as real time audio and video communication. It means that reserved bandwidth, priority and other Quality of Service properties shall be supported.

3.2.5 Telemetry

The telemetry module is connected via a telemetry interface to the transmitter. Packet size of telemetry data is usually not more than 64 kbytes, data rate not more than 10 Mbit/s.

3.2.6 RIU (Remote Interface Unit)

The Remote Interface Unit is connected to local router via SpaceWire.

Inside the RIU a controller configures and controls the connected sensors and actuators. The sensor and actuators are linked to the controller via its local bus (Milbus 1553b, Can-bus, RS422 etc.) or via discrete wires. The RIU collects housekeeping data and transmits the housekeeping data via SpaceWire to the telemetry system and/or to the onboard computer.

Large amount of sensors, which can produce interrupt signal require from network ability to transfer them to onboard computer.

3.2.7 Types of communications

Summarizing one can list the following types of data communications for piloted spacecraft:

- Data-handling network audio and video streams, etc.;
- Control bus for commands to devices and equipment of spacecraft;
- Telemetry bus for collecting housekeeping information (status, temperature, etc.) from devices on the spacecraft.
- Computer bus for data exchange between computer modules;
- Time-synchronization bus for clock synchronization.
- Side-band signal lines for interrupt acquisition from sensors.

3.3 Small satellite

Small satellite is much like a scientific satellite or earth observer as it is a kind of it. At the same time, it has some features to achieve minimum weight and size. First of all, an integrated payload, which includes instruments, data memory and transmitter. Avionic of small satellite shall also be maximally integrated to one unit at the limit. Integration of modules can be implemented by backplane instead of cables.

The use of galvanic isolation is not required due to small size of satellite.

The main requirements for small satellites are reducing the weight and complexity of the cables, as well as reducing power consumption.

A structure of small satellite network is shown on Figure 3.

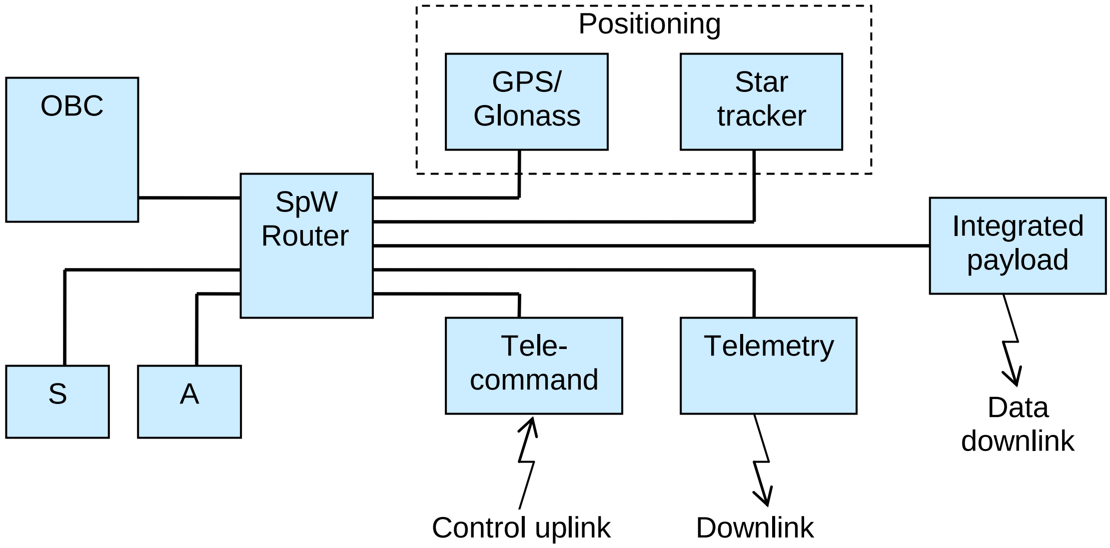

Figure 3 – small satellite network structure

3.3.1 Onboard computer

On-board computer of small satellite usually contains two redundant modules, one of which works and the other is cold standby. The management structure of a small satellite has one level which does not contain RIU. Sensors and actuators are controlled directly by OBC.

3.3.2 Router

Functions of router are similar to scientific satellite with exception of data transfer from instruments, as they are integrated into payload. At the same time router must transmit timestamp received from the GPS/Glonas for accurate bind of payload captures to the current position of the satellite.

3.3.3 Positioning

Positioning subsystem includes GPS/Glonass sensor for position and precise time determination and star tracker for precise orientation.

3.3.4 Tele-command/Telemetry

Tele-command subsystem provides direct control from Earth via uplink, including switching on-board computer modules.

3.3.5 Sensors and actuators

Due to satellite's small size there is no need to use Remote interface units. SpaceWire interface in this case shall be incorporated directly to sensors and actuators. This is possible due to the simplicity and low costs of SpaceWire interface units. The simplicity and low cost in this case are the requirements to SpaceWire-RT.

3.3.6 Types of communications summary

Following types of data communications are used in small satellites:

- Data-handling at moderate data rates;
- Control bus for commands to devices and equipment;
- Telemetry bus for collecting housekeeping information from devices on the satellite.
- Computer bus for data exchange between computer modules;
- Time-synchronization bus for clock synchronization.
- Side-band signal lines for interrupt acquisition from sensors.

Small satellite was included into use cases to present the need of LIGHT version of SpaceWire-RT, preserving all functional requirements, but without extreme data rates requirement, without costly in all senses galvanic isolation, with low power, cost and complexity, that allows designers to include SpW-RT to any sensor or actuator, intellectual or not.

4 Requirements from Russia

On the basis of the analysis of the questions which require the solution in the work program of SpaceWire-RT project, Research Institute "Submicron" and "Astrium" have developed the following tables that allow to extract additional requirements for the development of SpaceWire protocol on the part of the main manufacturers of space vehicles and equipment of the Russian federation and European Union and, subsequently, to carry out a generalized analysis of these requirements.

Definitions

The following definitions are used in the requirement chapters.

SpaceWire-RT shall support the following types of network functionalities:

- **Data-handling** network for connecting instruments to mass-memory units, data compressors, signal processor, etc;
- **Control bus** for commands from control modules to devices and equipment of spacecraft;
- **Telemetry bus** for collecting housekeeping information (status, temperature, etc.) from devices on the spacecraft;
- **Computer bus** for data exchange between computer modules in the course of data and signal processing;
- **Time-synchronization bus** for space-borne clock synchronization;
- **Side-band signal** lines for signaling and control in hard real time.

List of terms:

- **Message** – parcel of information, treated by the source as a single whole, which is subject to transmission; During transmission it can be divided into smaller parcels (for example, packets);
- **Validity** – probability that the received message coincides with the message which should be sent from the source;
- **Reliability** – ability of the network to work properly with specified probability of failure-free operation;
- **Broadcast transmission** – a transmission to multiple, unspecified recipients;
- **Multicast transmission** – a transmission mode in which a signal or packet is sent to multiple receivers, but not all receivers on a network;
- **Multi-path sending** – sending of message simultaneously via several specified routes;

List of the Russian manufacturers / institutions that were consulted during the requirements gathering for SpW-RT development:

- Open Joint Stock company “Military and Industrial Corporation NPO Mashinostroyenia”;
- Federal State Unitary Enterprise “Central Research Institute of Machine Building”;
- Federal State Unitary Enterprise “Khrunichev State Research and Production Space Centre”;
- Federal State Unitary Enterprise “Moscow Development design office “MARS”;
- “S.P.Korolev Rocket &Space Corporation Energia” Public Limited Corporation;
- The Joint-stock Company “Academician M.F.Reshetnev “Information Satellite Systems”;
- Federal State Unitary Enterprise “State Research and Production Space-Rocket Centre “TsSKB-Progress”;
- Federal State Unitary Enterprise “NPO n.a. S.A.Lavochkin”;
- “Electronic VLSI Engineering &Embedded systems”

Expert evaluations and typical proposals for parameters of different types of networks of advanced space vehicles subject to conversion to SpaceWire-RT technology from Russian Federation space industry manufacturers are presented in Table 2.

Table 2

Type of network functionality	**Distance** What maximum distance should the single network link operate over?	**Galvanic isolation** Is galvanic isolation required? What is the application for this?	**Specific transmission medium**	**Maximum user data rate**	**Maximum size of message**
Data-handling	10 m (1) 50 m (2) 3 m (3)	Yes (1,2) R≥100 Mohm, U≥200V No (3)	Coax cable, Fiber, STP	20 Gbit/s (1) 100 Mbit/s (2) 400 Mbit/s (3)	>10 Mb (1) 10 Mb (2) 2 Mb (3)
Control bus	30 m (1) 100 m (2) 10 m (3)	Yes (1,2) R≥100 Mohm, U≥200V Optionally (3)	STP, Fiber	10 Mbit/s (1) 10 Mbit/s (2) 1 Mbit/s (3)	1 Kb (1) < 1 Mb (2) 400 bytes (3)
Telemetry bus	30 m (1) 100 m (2) 10 m (3)	Yes (1,2) R≥100 Mohm, U≥200V Optionally (3)	TP, STP, Fiber	10 Mbit/s (1) 10 Mbit/s (2) 0,1 Mbit/s (3)	<10 Mb(1) <500 Kb (2) <100 Kb (3)
Computer bus	3 m (1) 6 m (2) 1 m (3)	Optionally (1,2,3)	STP, Backplane	400 Mbit/s (1) 10 Gbit/s (2) 5 Mbit/s (3)	1 Mb
Time synchronization bus	30 m (1) 100 m (2) 10 m (3)	Yes (1,2) R≥100 Mohm, U≥200V No (3)	TP, STP	< 10 Mbit/s	<1 K
Side-band signal	30 m (1) 100 m (2) 10 m (3)	Yes (1,2) R≥100 Mohm, U≥200V No (3)	TP, STP	<100 Mbit/s	<1 K
Comments	(1) – Earth observer (2) – Piloted spacecraft (3) – Small satellite	(1) – Earth observer (2) – Piloted spacecraft (3) – Small satellite	TP – twisted pair STP – shielded twisted pair	(1) – Earth observer (2) – Piloted spacecraft (3) – Small satellite	(1) – Earth observer (2) – Piloted spacecraft (3) – Small satellite

Table 2 - continued

Type of network functionality	Message rate (number per second)	Latency (taking into account communications queue)	Validity	Reliability	Necessity of message priorities	Necessity of broadcast transfers	Necessity of multi-cast transfers
Data-handling	<1000 (1) <100 (2,3)	<5 ms	high	high	no	no	yes
Control bus	<100 (1) <1000 (2) <10 (3)	<0,1 ms	high	high	yes	yes	yes
Telemetry bus	<10000	<5 ms	high	high	no	no	no
Computer bus	$<10^6$	<0,1 μs *	high	high	no	yes	yes
Time synchronization bus	<1000	<1 μs	high	high	yes	yes	yes
Side-band signal	<10000	<1 μs	high	high	yes	yes	yes
Comments	(1) – Earth observer (2) – Piloted spacecraft (3) – Small satellite	* - For single link (point to point communication)	Quantitative value not specified	Quantitative value not specified			

Table 2 - continued

Type of network functionality	Necessity of automatic acknowledgements	Necessity of multi-path sending	Necessity of automatic fault detection	Necessity of automatic fault identification	Necessity of failure an fault tolerance of network	Necessity of out of band messages
Data-handling	no	no	yes	yes	yes	no
Control bus	yes	yes	yes	yes	yes	yes
Telemetry bus	no	no	yes	yes	yes	no
Computer bus	no	yes	yes	yes	yes	no
Time synchronization bus	no	yes	yes	yes	yes	yes
Side-band signal	yes	yes	yes	yes	yes	yes
Comments				Can be software implemented		

5 Requirements from Europe

Table 3 below summarizes the initial requirements of SpaceWire-RT from European Union space manufacturers.

5.1 European companies provided feedback

The following European companies provided inputs to the initial set of requirements for SpaceWire-RT:

- RUAG Sweden
- Tesat
- Astrium Space Transportation
- Astrium Satellites Telecom
- Astrium Satellites Earth Observation, Navigation and Science
- Astrium Satellites Products

Table 3

Fields of application	*Data-handling network*	*Control bus*	*Telemetry bus*	*Computer bus*	*Time-synchronization bus*	*Side-band signal*	*Comments/ Remarks*
Distance: What range of distances should the network operate over?	10 m	10-50 m	10 m	1 m	10 m	-	
	2-4 m						
	10 m						
	12 m				12 m		
AC coupling: Is AC coupling of the communication link required for reduced EMC emissions?	No	For long distance	No	No	No	-	
	optionally						
Galvanic isolation: Is galvanic isolation required where the chassis grounds of the two pieces of equipment connected by the network are isolated? What is the application for this?	No	For long distance. Application: Launcher	No	No	No	-	
	optionally						
	yes	yes	yes	yes			
Specific transmission medium: Are there any specific transmission media that you would require or prefer, e.g. twisted pair, screened twisted pair, co-ax, optical fibre? Please state why.	STP, Fibre (speed)	STP, Fibre (galv isol)	STP	STP, Fibre (speed)	STP	-	
	Twisted pair if possible, Otherwise co-ax Reason: cost						
	STP						

Fields of application	*Data-handling network*	*Control bus*	*Telemetry bus*	*Computer bus*	*Time-synchronization bus*	*Side-band signal*	*Comments/ Remarks*
Specific coding mode: Is there any requirement for a specific method of coding, or any requirements on the coding method? If so why?	No	DC bal when using galv isol.	No	No	No	-	
	Line code (TBD) in order to prevent transmission errors						
	no	no	no	no			
Maximum user data rate (Mbytes/s): what is the maximum user data rate for each type of bus/network, or range of maximum user data rates? For data rates higher than 20 Mbytes/s what is the main application?	> 500	20	20	> 500	< 1	-	
	100 – 200 Mbit/s reason: reduce time latency			If used for inter-ASIC data transfer, i.e. SERDES type arrange-ment, would be likely to require multiple parallel links. Total rate per link to be as many Gbps as possible			
	2 Gbit/s for connecting mass memory with downlink modulators						
	10 Mbps	10 Mbps	100 Mps Payload TM	10 Mbps	10 Mbps		

Fields of application	*Data-handling network*	*Control bus*	*Telemetry bus*	*Computer bus*	*Time-synchronization bus*	*Side-band signal*	*Comments/ Remarks*
Typical message size (bytes):	1KB – 64 KB	128 B	256 B	1 KB- 1 MB	1 B	-	
What is the typical size of message that needs to be transferred over the network?	260 bytes	260 byte	300 bytes				
Typical message rate (number per second): How many typical sized messages per second?	50000	200	500	10000	256	No need for using signalling at shorter latencies than the time synchronisatio n resolution	
	1568 bytes (CCSDS packet)						
	100	10	100				
Minimum packet size: What is the minimum packet size? What is this used for?	20 B (ctrl cmd)	10 B (simple cmd)	20 B (cmd ack. TM)	20 B (ctrl cmd)	1	-	
	64 byte (IP packet)						
		Approx 10 bytes. setting control registers					
	17 bytes	17 bytes	17 bytes	17 bytes			

Fields of application	*Data-handling network*	*Control bus*	*Telemetry bus*	*Computer bus*	*Time-synchronization bus*	*Side-band signal*	*Comments/ Remarks*
Minimum packet rate: How many of these small packets are sent per second?	100	20	20	100	1	-	
		<1000 in occasional bursts. Typically far fewer in steady state operation					
	200	100	100	100			
Maximum packet size: What is the maximum packet size? What is this used for?	> 1 MB Raw images	1 KB Memory load cmds	64 KB Memory dump	> 1 MB Raw images	1	-	
		Several Kbytes. Configuring control RAMs					
	4000 bytes	4000 bytes	4000 bytes	4000 bytes			
Maximum packet rate: How many of these large packets are sent per second?	10	2	< 1	10		-	
		100, in occasional bursts					
	50	50	50				

Fields of application	*Data-handling network*	*Control bus*	*Telemetry bus*	*Computer bus*	*Time-synchronization bus*	*Side-band signal*	*Comments/ Remarks*
Power consumption:	200 mW	100 mW	50 mW	200 mW	50 mW	-	
What is an acceptable maximum power consumption per link (two interfaces)?	<< 1 W						
	2 W						
Mass interconnect: What is an acceptable mass for the cable per m?	60 g	30 g	30 g	60 g	30 g	-	
Maximum propagation time: Are there any?						-	
Skew, coherence: Are there any requirements on when different signals (message, broad cast packet, time-code) sent at the same time arrive at different destinations?						-	All data shall arrive in the same order as sent
Phase Jitter of data signal:		< 5 µs jitter			< 0,2 µs jitter	-	
Is this important to any of your applications?		< 1 ms			< 1 µs (see jitter)	-	
Maximum latency: What is the maximum permitted delay from source user application to destination user application taking into account communication queue delays?	10 msec						

Fields of application	*Data-handling network*	*Control bus*	*Telemetry bus*	*Computer bus*	*Time-synchronization bus*	*Side-band signal*	*Comments/ Remarks*
Validity: How important is it that the message that arrives at a destination coincides with the message sent from a source? Please express this as a percentage of correctly received messages.		Message error rate < 10^{-11}				-	The bit error rate should not exceed 10^{-14} for any link
		Very important		important		Very important	
	50%						.
Reliability: If a message is not correctly delivered should it be the responsibility of the network or the application to resend that information assuming that the information is important?	Application	Application	Application	Application	Application	-	
	Network, however configurable, means also application						
	No						
		Network to attempt a fix, e.g retry. Application to ensure a fix if this fails		network		Network to attempt a fix, e.g retry. Application to ensure a fix if this fails	
	Yes if possible						

Fields of application	*Data-handling network*	*Control bus*	*Telemetry bus*	*Computer bus*	*Time-synchronization bus*	*Side-band signal*	*Comments/ Remarks*
Automatic acknowledgement: For some messages is an automatic acknowledgement of receipt at the destination required?	No	Useful but not necessary	No	No	No	-	
	Yes sometimes, do it configurable						
		yes				yes	
	yes						
When to acknowledge: Should the acknowledgement be on correct receipt of the entire message into a message buffer or when the destination user application completes reading the message from the message buffer?	-	When the receiving application has executed the message	-	-	-	-	
	Should be on correct receipt of the entire message in the first buffer						
		When read from buffer preferred				When read from buffer preferred	
	yes						

<table>
<tr><th>Fields of application</th><th>Data-handling network</th><th>Control bus</th><th>Telemetry bus</th><th>Computer bus</th><th>Time-synchronization bus</th><th>Side-band signal</th><th>Comments/ Remarks</th></tr>
<tr><td rowspan="5"><u>Multipath transmission:</u>
Is it important to be able to send the same message over different routes through the network/bus for reliability purposes?
What applications require this?</td><td>No</td><td>For a few time critical commands, e.g. booster separation commands</td><td>No</td><td>No</td><td>No</td><td>-</td><td></td></tr>
<tr><td>Sometimes yes, fault tolerance</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>no</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Nice to have</td><td></td><td></td><td></td><td>Nice to have</td><td></td></tr>
<tr><td>no</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="5"><u>Automatic fault detection and identification:</u>
Should the network/bus be able to detect, identify and report when a fault occurs?
Does this apply to both transitory (occur occasionally), persistent (occur often), and permanent (occur always) faults?</td><td colspan="4">Yes
Applies to any fault. The type of fault is then determined by the applications</td><td>No</td><td>-</td><td></td></tr>
<tr><td>Yes, it should do this</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>yes</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Yes, all faults</td><td></td><td>Yes, all faults</td><td></td><td>Yes, all faults</td><td></td></tr>
<tr><td>yes</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Fields of application	*Data-handling network*	*Control bus*	*Telemetry bus*	*Computer bus*	*Time-synchronization bus*	*Side-band signal*	*Comments/ Remarks*
Failure and fault tolerance of network: Should the network be able to automatically recover from transitory, persistent and permanent faults?	Not necessary, but a nice feature	No	No	No	No	-	
	Yes, it should do this						
	yes						
		Nice to have – not essential		Nice to have – not essential		Nice to have – not essential	
	yes						
Desired fault model of software:						-	
Message priority: Is it necessary to send some messages with higher priority than others? For what application?	No	No, each virtual channel shall have a minimum reserved bandwidth on the network	No, each virtual channel shall have a minimum reserved bandwidth on the network. The sending application then prioritizes within VC	Maybe, to signal control information	No	-	

Fields of application	*Data-handling network*	*Control bus*	*Telemetry bus*	*Computer bus*	*Time-synchronization bus*	*Side-band signal*	*Comments/ Remarks*
Message priority: continued	Yes , broadband applications with quality of service						
		Yes, if single link used for both control and data packets					
	Yes, High priority telecommand						
Determinism: Is it necessary to be able to deliver messages within specified time windows? For what application?	Yes, to allow instruments without buffering capability to send data at regular internals	Yes. To control non-intelligent actuators	Yes, to receive data from non-intelligent sensors	No	Yes, To ensure that time data is sent in due time before a specific time tick.	-	
	Yes, fault tolerance & broadband communica-tion						

Fields of application	*Data-handling network*	*Control bus*	*Telemetry bus*	*Computer bus*	*Time-synchronization bus*	*Side-band signal*	*Comments/ Remarks*
Bandwidth reservation: Is it useful to be able to reserve bandwidth over a link, network, or bus for transfer of specific data? What type of data?	Yes, to ensure that at least some data from each node will pass through the system	Yes	Yes	No	No (but see the determinism answer)	-	
	Yes, broadband communica-tion	Sounds useful if control and data packets use the same link					
Broadcast data transfer: Is the sending of messages to all nodes on the network required? If so what for?	No, but multicasting to the mass memory and a data processor in parallel would be useful.	Partly. It must be possible at three to four points to monitor all data on the network	Partly. It must be possible at three to four points to monitor all data on the network	No	Yes. To distribute the time data and the time ticks.	-	
	Yes, for network synchronisa-tion messages	Potentially useful for a soft reset or mode change					

Fields of application	*Data-handling network*	*Control bus*	*Telemetry bus*	*Computer bus*	*Time-synchronization bus*	*Side-band signal*	*Comments/ Remarks*
Out-of-band signals: What out-of-band signals are required e.g. time-codes, interrupts?	Time ticks	Time ticks	Time ticks	Time ticks	Time ticks	-	
						Interrupts are essential	
Out-of-band information: What information needs to be transferred with the out-of-band signals?	Time, typically 48 bits + 16 control bits	Time, typically 48 bits + 16 control bits	Time, typically 48 bits + 16 control bits	Time, typically 48 bits + 16 control bits	Time, typically 48 bits + 16 control bits	-	
						Interrupt needs to identify source node plus node status information	
Network debugging tools: What network debugging tools do you consider essential?	Network message spy (selected by user), Network load & Data traffic monitor, Data source generator	Network message spy (all messages), message coverage (i.e. are all messages transmitted)	Network message spy (all messages), message coverage (i.e. are all messages transmitted)	Network message spy (selected by user), network load monitor	Network message spy with accurate - timing of messages	-	
Network testing tools: What tools are required to test and validate a network?	Same as debugging	Same as debugging	Same as debugging	Same as debugging	Same as debugging	-	

6 RF and EU consolidated requirements

In this section the requirements for SpaceWire-RT are presented, consolidated from the requirements inputs from RF and EU.

6.1 Data Rate

REQ-10 Data Rate (data handling)

SpW-RT shall be capable of data rates up to 20 Gbits/s.

Rational: this is necessary to support high data rate Earth observation missions like imagers or synthetic aperture radar.

REQ-11 Data Rate (all others)

SpW-RT shall be capable of data rates up to 400 Mbits/s.

Rational: this is necessary to get a low latency in routing elements. For the pure data throughput SpW-RT could also run on lower data rates.

6.2 Distance

REQ-20 Distance (control bus)

SpW-RT shall operate over a distance of up to 100 m.

Rational: this is necessary to use SpW in launcher and piloted spacecraft applications where equipment may be arranged in a larger distance.

REQ-21 Distance (all others)

SpW-RT shall operate over a distance of 1 m to 10 m.

Rational: this is necessary to operate on high data rates which a small to moderate distance and the equipment is close together.

6.3 Galvanic isolation

REQ-30 Galvanic isolation (control bus)

SpW-RT shall provide galvanic isolation.
Isolation Resistance Ris ≥ 100 Mohm
Breakdown Voltage Vbd ≥ 250 V

Rational: this is necessary to support long distance applications like launchers or test equipment. If galvanic isolation is implemented an appropriated coding mode has to be used resulting in a DC-balanced output.

REQ-31 Galvanic isolation (all others)

SpW-RT may provide galvanic isolation.

Rational: most of the other applications are located inside a unit or box where galvanic isolation is often not required.

In EU there is only a need for galvanic isolation in long distance applications but in Russian Federation (RF) galvanic isolation is a most common requirement.

6.4 Transmission medium

REQ-40 Transmission medium (data handling, control bus, computer bus)

SpW-RT shall operate on twisted pair, co-ax or fibre.

Rational: this is necessary to run over existing network infrastructure also.

REQ-41 Transmission medium (telemetry bus)

SpW-RT shall operate on twisted pair.

Rational: twisted pair is sufficient for lower data rates and has lowest cost.

6.5 Packet size

REQ-50 packet size (data handling, computer bus)

SpW-RT shall support application packet sizes up to at least 32 Mbytes.

Rational: Application packets of up to 32 Mbyte are used for transferring raw data.

REQ-51 packet size (control bus, telemetry)

SpW-RT shall support packet sizes in the range from 8 bytes to 64 Kbytes.

Rational: The minimum packet size is used for control commands; e.g. an RMAP write reply packet has 8 bytes. Packet sizes between 1 Kbyte and 64 Kbytes are used in memory load/dump commands.

6.6 Maximum latency

REQ-60 Maximum latency (control bus)

SpW-RT shall support a maximum latency of less than 100 µs.

Rational: low latency is necessary for transferring command packets through the network in real time applications.

REQ-61 Maximum latency (time synchronization bus)

SpW-RT shall support a maximum latency of up to 100 ns.

Rational: this is necessary to implement accurate time distribution system.

REQ-62 Maximum latency (computer bus)

SpW-RT should support a maximum latency of less than 100 ns over a single link.

Rational: low latency is necessary for communication between two processor modules.

6.7 Reliability

REQ-70 reliability

SpW-RT shall provide a capability for reliable data delivery

Rational: some data is critical and must be delivered without corruption.

6.8 Determinism

REQ-80 determinism

SpW-RT shall provide determinism.

Rational: this is necessary to control non-intelligent actuators and to receive data from non-intelligent sensors. Determinism allows instruments to send regular data without internal buffering.

6.9 Validity

REQ-90 validity

SpW-RT shall support a message bit error rate of less than 10-15.

Rational: this is necessary to reduce the effort for re-ordering on the receiving side.

This is seen as very important for control buses and important for computer buses.

6.10 Automatic acknowledgement

REQ-100 automatic acknowledgement (control bus)

SpW-RT should support configurable automatic acknowledgement.

Rational: this is necessary to control non-intelligent actuators and non-intelligent sensors.

6.11 Automatic fault detection and identification

REQ-110 Automatic fault detection

SpW-RT shall support automatic fault detection.

Rational: a fault should be detected as early as possible to avoid failure propagation.

This applies to any type of failure: transitory (occur occasionally), persistent (occur often) and permanent (occur always).

REQ-111 Automatic fault identification

SpW-RT may support automatic fault identification.

Rational: fault identification can be left to application. Sometimes it can be difficult to decide in hardware the nature of fault.

6.12 Failure and fault tolerance of network

REQ-120 failure and fault tolerance of network (data handling network)

SpW-RT network should be able to automatically recover from faults.

Rational: automatically recovery from faults can be handled in most applications by software. In specific applications where short reaction time is an issue, automatically recovery may be implemented on network level.

6.13 Multi-path transmission

REQ-130 multi-path transmission (control bus)

SpW-RT shall support multi-path transmission.

Rational: this is necessary for time critical commands, e.g. booster separation command.

6.14 Broadcast data transfer

REQ-140 broadcast data transfer (time synchronisation bus)

SpW-RT shall support broadcast data transfer.

Rational: this is necessary to distribute the time data and the time ticks.

6.15 Multi-cast data transfer

REQ-150 mulit-cast data transfer (computer bus)

SpW-RT shall support multi-cast data transfer.

Rational: this is necessary to deliver the same data to the devices in the redundant system.

6.16 Out-of-band signals and information

REQ-160 out-of-band signals

SpW-RT shall transfer time-ticks and interrupts with very short latency.

Rational: this is necessary to replace single wires used for distributing the time ticks and interrupts.

6.17 Mass interconnect

REQ-170 mass interconnect

Mass interconnect shall be less than 30 g/m (for one lane)

Rational: this is necessary to reduce the mass of the harness which could be a significant part of the total mass.

6.18 Power consumption

REQ-180 power consumption

The power consumption of a lane (two interfaces) should be in the range of 50 mW to 200 mW.

Rational: The power consumption has to be as low as possible because it sums up with the number of link interfaces.

6.19 Communication

REQ-190 Communication

SpW-RT shall support the communication requirements as described in the table below.

Rational: Table 4 below summarizes the major communication characteristics in a quantitative way which can occur.

Table 4 – communication requirements

	Distance	Rate	Latency	Packet size	QoS
Data-handling network	Short to long	Low to very high	Not important	Short to long	Reserved bandwidth
Control bus	Short to long	Low	Low	Short to long	Deterministic delivery
Telemetry bus	Short to long	Low	Low	Short	Reserved bandwidth
Computer bus	Short	Very high	Low	Short to long	Reserved bandwidth
Time-sync bus	Short to long	Low	Very low	Short	High priority
Side-band	Short	Low to high	Very low	Short	High priority

7 Analysis of feedback from SpaceWire working group

RF and EU consolidated requirements were presented at the Seventeenth Working Group Meeting.

Feedback from the Working group includes the following additional requirements:

- Network size (i.e. maximum number of nodes) should be defined;
- Multi-master capability (initiation of transfers by multiple users);
- Transaction security;
- Network testability.

7.1 Network size

Current logic addressing may become a restriction for large complexes. The problem is especially serious when two complexes shall be connected and work together in space. Connecting spacecraft network to International Space Station network is an example. Extended addressing shall be considered in SpaceWire-RT project.

7.2 Multi-master capability

Multi-master capability is not prohibited in current standard, but on the other hand it is not defined. New SpaceWire-RT standard shall clarify this capability.

7.3 Transaction security

Transaction security is necessary to protect network from faulty units as well as it helps in debugging. It may include specification of packet source address in the packet and other protection mechanisms. The main problem is to keep compatibility with current standard. Anyway transaction security shall be seriously considered in SpaceWire-RT project.

7.4 Network testability

SpaceWire-RT compliance test (procedure) shall be developed and included into standard, although this is outside the scope of the current SpaceWire-RT activity;

Using of proven SpaceWire-RT compliant devices is necessary for minimizing assembly and debugging time for large complexes.

8 Summary and conclusions

For provision of information to the main manufacturers of space vehicles and equipment of the Russian Federation the following measures were taken:

1) the reports concerning the questions of development of computer system architecture of advanced space vehicles on the basis of the SpaceWire technology were made on the Scientific and Technical Council of Roscosmos (the Russian Federal Space Agency);

2) two seminars were held on the enterprises of Roscosmos with reports of the leading executors of this project concerning the fundamentals of the existing SpaceWire technology and its further development in the SpaceWire-RT program;

3) there was created a Working Group within the Scientific and Technical Council of Roscosmos for selection of space-borne interfaces in order to unify the development of space-borne equipment of space vehicles for national and international projects;

4) Roscosmos made a decision to create a national working group for introduction of the SpaceWire technology into branch-wise pilot projects and for development of the national SpaceWire standard;

5) a list of components necessary for creation of the computer system of space vehicles is being formed and agreement of Technical Design Specification for development and creation of these components in accordance with the state programs of the Russian Federation is carried out.

6) the materials concerning the SpaceWire technology are sent to the main manufacturers of space vehicles and equipment of the Russian Federation.

7) a formalized list of questions concerning the problem of updating the requirements to the SpaceWire-RT protocol was formed, and it was sent to the main manufacturers of space vehicles and equipment of the Russian Federation and the enterprises of the European Union (via the “Astrium” company).

The Research Institute “Submicron” gathered and analyzed the information received from the developers of the space-borne equipment and formulated the requirements to the program of SpaceWire-RT development.

Initial requirements and use cases from EU organizations were obtained and integrated with those from RF organizations. Combined set of initial requirements was provided to consortium contributors for discussion and become an input for to presentation to the Seventeenth International SpaceWire Working Group.

Feedback from contributors as well as from International SpaceWire working group was taken into account in this report.

The analysis of Working Package 1 results shows that the SpaceWire-RT research program meets the requirements and scenarios of the SpaceWire-RT technology usage in advanced space vehicles, made in the Russian Federation or in the European Union, and removes restrictions in the current SpaceWire technology.

9 Appendixes

9.1 Appendix 1: Requirement Questionnaire

The following Questionnaire was sent to European and Russian space companies to gather requirements for SpaceWire-RT:

The following questions cover a wide range of technologies and applications please feel free to answer only those that you have appropriate knowledge and experience of. A partially complete form is much more use to us than no form at all. Please answer each question for each of the different buses/link/network types that you have experience of.

Definition of Applications:

- **Data-handling network** for connecting instruments to mass-memory units etc.
- **Control bus** for commands from control modules to devices and equipment of spacecraft.
- **Telemetry bus** for collecting housekeeping information (status, temperature, etc) from devices on the spacecraft.
- **Data bus** for data exchange between computer modules in the course of data and signal processing.
- **Time-synchronisation bus** for space-borne clock synchronisation.
- **Side-band signal** for signalling and control in hard real time.

FIELDS OF APPLICATION	*Data-handling network*	*Control bus*	*Telemetry bus*	*Data bus*	*Time-synchronization bus*	*Side-band signal*	*Comments/Remarks*
Distance: What range of distances should the network operate over?							
AC coupling: Is AC coupling of the communication link required for reduced EMC emissions?							*
Galvanic isolation: Is galvanic isolation required where the chassis grounds of the two pieces of equipment connected by the network are isolated? What is the application for this?							
Specific transmission medium: Are there any specific transmission media that you would require or prefer, e.g. twisted pair, screened twisted pair, co-ax, optical fibre? Please state why.							
Specific coding mode: Is there any requirement for a specific method of coding, or any requirements on the coding method?							

If so why?							
Maximum user data rate (Mbytes/s): what is the maximum user data rate for each type of bus/network, or range of maximum user data rates? For data rates higher than 20 Mbytes/s what is the main application?							
Typical message size (bytes): What is the typical size of message that needs to be transferred over the network?							*
Typical message rate (number per second): How many typical sized messages per second?							
Minimum packet size: What is the minimum packet size? What is this used for?							*
Minimum packet rate: How many of these small packets are sent per second?							*
Maximum packet size: What is the maximum packet size? What is this used for?							
Maximum packet rate: How many of these large packets are sent per second?							
Power consumption: What is an acceptable maximum power consumption per link (two interfaces)?							*
Mass interconnect: What is an acceptable mass for the cable per m?							*
Maximum propagation time: Are there any?							
Skew, coherence: Are there any requirements on when different signals (message, broad cast packet, time-code) sent at the same time arrive at different destinations?							
Phase Jitter of digital data signal: Is this important to any of your applications? If so what applications?							
Maximum latency: What is the maximum permitted delay from source user application to destination user application taking into account communication queue delays?							
Validity: How important is it that the message that arrives at a destination coincides with the message sent from a source? Please express this as a percentage of correctly received messages.							

Reliability: If a message is not correctly delivered should it be the responsibility of the network or the application to resend that information assuming that the information is important?							
Automatic acknowledgement: For some messages is an automatic acknowledgement of receipt at the destination required?							
When to acknowledge: Should the acknowledgement be on correct receipt of the entire message into a message buffer or when the destination user application completes reading the message from the message buffer?							
Multipath transmission: Is it important to be able to send the same message over different routes through the network/bus for reliability purposes? What applications require this?							
Automatic fault detection and identification: Should the network/bus be able to detect, identify and report when a fault occurs? Does this apply to both transitory (occur occasionally), persistent (occur often), and permanent (occur always) faults?							
Failure and fault tolerance of network: Should the network be able to automatically recover from transitory, persistent and permanent faults?							
Desired fault model of software:							
Message priority: Is it necessary to send some messages with higher priority than others? For what application?							
Determinism: Is it necessary to be able to deliver messages within specified time windows? For what application?							*
Bandwidth reservation: Is it useful to be able to reserve bandwidth over a link, network, or bus for transfer of specific data? What type of data?							
Broadcast data transfer: Is the sending of messages to all nodes on the network required?							

If so what for?							
Out-of-band signals: What out-of-band signals are required e.g. time-codes, interrupts?							
Out-of-band information: What information needs to be transferred with the out-of-band signals?							
Network debugging tools: What network debugging tools do you consider essential?							
Network testing tools: What tools are required to test and validate a network?							

* Comment: This question is not included in the Russian Questionnaire.

9.2 Appendix 2: Use case Template

The following Template was sent to European space companies to gather use cases SpaceWire-RT:

Applications and Missions for SpW-RT in a spacecraft

Below you find some *examples* of applications where SpW-RT can be used. Please **complete** the table with your important criterias and feel free to **add** further applications where SpW-RT could be used from your point of view.

Application/Mission	**Important criteria like: Reliable, timeliness, robust, etc.**	**Comments**
AOCS systems		
Multi-processor architectures		
Multi-processor architectures		
Multi-instruments environments		
Multi-instruments environments		
High performance mass memories		
High performance mass memories		
Onboard data processing system		