

# SPACEWIRE ROUTER IP-CORE WITH PRIORITY ADAPTIVE ROUTING\*

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**Abstract.** Design of modern spacecraft focuses on using network principles of interaction on-board equipment, in particular in network SpaceWire. Routers are an integral part of most SpaceWire networks. The paper presents an adaptive routing algorithm with a prioritization, allowing more flexibility to manage the routing process. This algorithm is designed to transmit SpaceWire packets over a redundant network. Also a method is proposed for rapid restoration of working capacity after power by saving the routing table and the router configuration in an external non-volatile memory. The proposed solutions used to create IP-core router, and then tested in the FPGA device. The results illustrate the realizability and rationality of the proposed solutions.

## 1. Introduction

Providing network communication of onboard equipment is a leading direction of Space Instrument development. The most important network technology for space applications is SpaceWire, widespread use of which has led to an emergence of many varieties of different network infrastructure devices such as routers, including in the form of IP-cores.

Lately kinds of router architectures and its functionality settled and generally the same for all providers. SpaceWire standard, in the main, does not allow of variation of the internal routers architecture. Differences are the types of external interfaces for accession to the host processors. The works [1-4] present examples of implemented on the basis of IP-core routers from several providers. Nevertheless, several important practical issues are not reflected in the architecture of routers. For example, the routers redundant network structure, when alternative SpaceWire channels are created to improve reliability and overall network throughput. Also an important attribute for a large redundant network is the ability of autonomous to preserve the configuration and routing tables when power is off of the router. Power may be disabled emergency or scheduled but in both cases is often important recovery rate of the router performance.

A task of this paper is to present solutions to these problems. The first problem is carried out with a help of a group adaptive routing, using prioritizations of router output ports; the second with the help of an external non-volatile memory of the router, which stores the current configuration and routing table.

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These decisions are reflected in the developed reconfigurable VHDL IP-core of router. On the basis of the IP-core were created stand-alone router, and the router built-in system-on-chip. The results confirmed rationality of the developed solutions.

## **2. Known solutions**

Reliability of the equipment is a prerequisite for space missions. Reliability of equipment is provided of hardware redundancy and reliability of the network is further provided redundancy of the paths. Fault tolerant architecture provides redundant paths for routing of packets.

Paragraph [5] show diagrams of the fault-tolerant networks when the core network are duplicated with its infrastructure components (routers) and nodes i.e. have the same primary and backup parts of the sub-networks. Nodes of main and redundant networks are linked with main and redundant routers. Fault tolerance is provided with the redundancy SpaceWire packages sent.

Section [6] demonstrate a fault tolerant topology scheme of a double star, where each node is considered as dual redundant, i.e. primary and redundant. The nodes can be hot redundant or cold redundant. It is proposed to use a special distributed fault tolerant routing protocol to support fault tolerant routing topology in [6]. To perform fault tolerant routing protocol all network devices should have the intelligent capability which makes network hardware more complex.

The work [7] consider several possible fault tolerant routing topologies, based on known types of network structures such as a double star, a double-double star, a triple star and similar. At least for small networks, e.g. for small spacecrafts, a double star are considered as most relevant solution. As well as [6] it is proposed to use one embodiment of a distributed adaptive routing algorithm. However, for the consideration of the small size of the network adaptive centralized routing [8] would be more appropriate.

In the above works fault tolerant topologies are supported by redundant network traffic. However, certain standard [9] group adaptive routing also can be used for reserving data channels. To do this, it must be supplemented prioritization output ports, which allows for the logical address of the packet arrived at the router is easy to determine the output port according to its priority and the lowest priority to reserve the output port corresponding SpaceWire channel. In this case, there is no redundancy of network traffic via additional redundant packets or routing protocol packets. This paper presents the rationale of the proposed solutions and supports its implementation in a router.

In addition, the known solutions sidestep the issue of minimizing delays recovery routing table and router configuration during power loss. Turning off the power of the router is very likely situation. It is assumed that the restoration of the router settings should provide the host computer. However, if the network is large, besides redundant, then the recovery process settings can be time consuming, that in some cases is unacceptable. The paper proposes to save the settings of the router in the external memory. When the router is turned on, its settings are loaded from the external memory, and network immediately becomes operational.

These solutions have been implemented in developed reconfigurable VHDL IP-core router. Four-port stand-alone router was created on the basis of IP-core. The results confirmed the effectiveness of the developed solutions.

## **3. Proposed solutions**

### *3.1. Group adaptive routing using prioritization output port*

Multiple output ports of the router to one logical address of the packet, received in the router, conform to redundancy channels. Group adaptive routing provides conformity of single logical address of group output ports. Selecting a particular output port of the group allows prioritization of ports.

Suppose one logical address corresponds to the four output ports. Each output port, can specify multiple priority levels, for example 4. When a packet arrives with this logical address it is sent to the port with the highest priority. If the port with the highest priority is busy, the packet is routed to the port with the lower priority level. If it is busy too, the packet is routed to the port with much lower priority level. If several free ports have the same priority level, the packet crossing in the port with the lowest port number.

The use of priorities is easiest to illustrate via tables. Fig. 1 shows the routing and priorities tables for the router, which has 4 ports.

	Address	Port 0	Port 1	Port 2	Port 3	Port 4
Routing	0	1	0	0	0	0
Path Addressing	1	0	1	0	0	0
	2	0	0	1	0	0
	...					
Logical Addressing	32	0	1	1	0	0
	33	0	0	0	1	1
	34	0	1	1	0	1
	...					
	255	0	0	0	0	0

	Address	Port 0	Port 1	Port 2	Port 3	Port 4
Prioritization	0	x	x	x	x	x
Path Addressing	1	x	x	x	x	x
	2	x	x	x	x	x
	...					
Logical Addressing	32	x	00	11	x	x
	33	x	x	x	10	11
	34	x	11	10	x	01
	...					
	255	x	x	x	x	x

**Figure 1.** Table of routes and priorities.

Logical address 32 has two output ports: port 1 and port 2. When receiving a packet with this address, it is routed to port 2 having a higher priority. If port 2 is busy, the packet will be forwarded to port 1 which has less priority. If the logical address has only 2 ports, it is enough only 2 priority levels: low and high. If the network is more redundant, the logical address may have more than 2 output ports, it is necessary to increase the number of priority levels. So the logical address of 34 has three output ports and each of them may have, in the general case, own priority. For most practical cases it is sufficient to have four levels of priority.

Multi-level prioritization can be used to prohibit using of certain ports without disconnecting them in a router. For example, you can set some ports the lowest priority level and prohibit their use. The packages will be sent to the ports with higher priority, and if these ports are busy, the packets will wait until they become free. Subsequently, if one of the channels connected to a port with high priority will refuse, ban on the use of the port with the lowest priority will be removed. Thus, actually made a reservation channels and manage their switching via group adaptive routing with prioritization of the ports. The method is very simple and easy to implement in the router.

Should be noted another point which previously discussed in part [8, p.99]. If the router simultaneously received two packages with different logical addresses for which the highest priority has the same port, to avoid conflict first access to the table will receive a package whose logical address is smaller. It takes the port with a higher priority, and the packet with a lower logical address will be sent to the port with lower priority.

Note also that to implement the storage of priorities easier just not as one table but as two tables, each of which stores only 1 bit of 2-bit representation of the priority level. Although other options are possible.

Thus, the algorithm group adaptive routing with prioritization of ports produces: backup of paths, switching to a backup paths, sending packets over paths with higher priority.

### *3.2. External backup router configuration*

When the router is turned off and then the power is restored immediately only path routing is available. In large networks with alternative data channels using path routing is impractical. The host computer performs recovery of logical addresses in the routing tables, a content of priority table and the configuration of the router. Redundant network has at least twice the number of routers. Therefore, this process can take a long time, during which the routers and the network as a whole inoperative. To minimize the recovery time of work is offered each router to equip with an external non-volatile memory. In this memory stores all the settings of the router that when power is restored very quickly loaded into the router, which almost immediately becomes ready for operation. The network will become operational faster than after you disconnect and restore power will boot of the host computer.

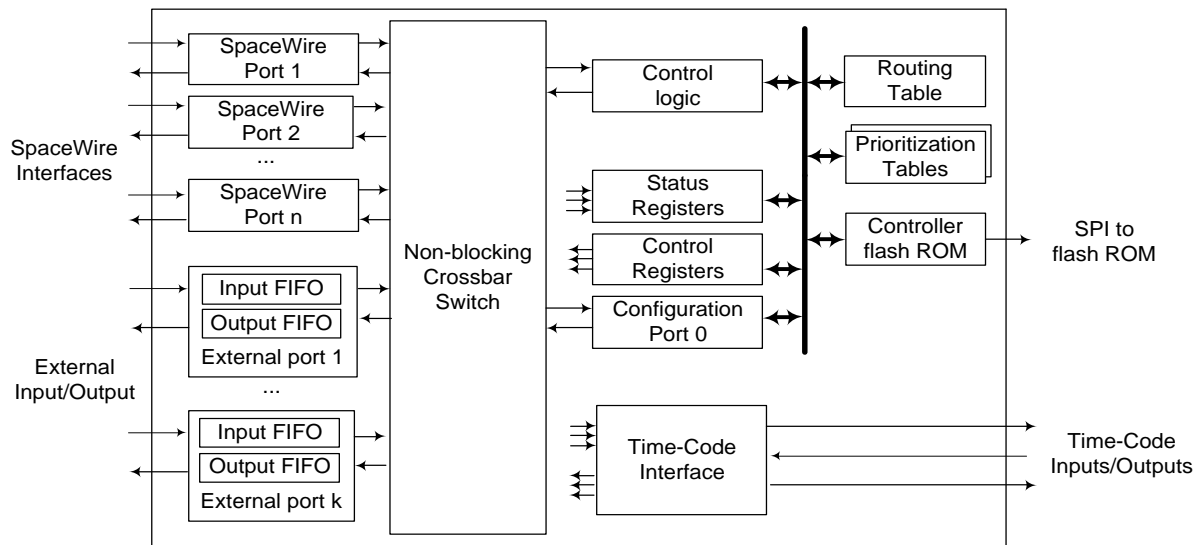
## **4. An example implementation**

The presented solutions have been implemented in reconfigurable router IP-core created in VHDL. Reconfiguration refers to the ability of choosing from the total possible number of ports required number of SpaceWire ports and FIFO interfaces synthesized for a specific router. Maximum number of ports SpaceWire ports and FIFO interfaces is 31. The rest of the structure is quite traditional router (Figure 2) with the exception of the components responsible for the implementation of the proposed solutions. Port priorities are stored in the priority tables. Request to the external memory which stores the configuration of the router by using a flash ROM controller via SPI interface.

All ports are connected to each other by using non-blocking switching matrix, which allows establishing a direct channel between them. And already established connections do not prevent the establishment of new, if switching ports free.

Using of regional-logical addressing involves the need to remove the first byte of transmitted package. For this purpose is using the register, in which sets the number of regional ports.

Additionally SpaceWire router supports broadcast distribution of packages over network. This function can be set for one or more logical addresses. Upon arrival of the package it will be sent to all the ports listed in the routing table for that logical address.



**Figure 2.** SpaceWire Router Block Diagram.

For configuration uses an internal zero port that supports the RMAP protocol in accordance with ECSS-E-ST-50-52C standard. RMAP-target allows you to read and write data directly into the registers of the router.

The router allows you to collect status information about a number of errors associated with errors routing of packet, a timeout of the port, breaks SpaceWire connection. Additionally, each port has its own status register in which is recording the detailed information about its condition.

Functional verification of the router, as well as RMAP-target, was carried out by creating full-featured models of testing environment in FPGA. The models consisted of a system-on-chip that include the device under test and one or more SpaceWire codec [9, 10]. These network devices communicate via external cables forming SpaceWire channels created in this way fragment of the network. Test software running on processor core system-on-chip, carried out exchange of a test packets, via which was verified of a router function.

## 5. Experimental results

For evaluation of FPGA resources which are required to accommodate the designed IP-core the router was synthesized in several configurations. As the FPGA Altera EP4CE115F29C7, Microsemi A3PE1500 and Microsemi RTAX2000 were used. The results of synthesis are shown in table 1. They can be considered satisfactory.

**Table 1.** Results of the synthesis of router in FPGAs.

Number of ports	Altera EPCE115F		Microsemi A3PE1500		Microsemi RTAX2000	
	Les,%	FFs,%	Cells,%	FFs,%	Cells,%	FFs,%
4	3	<1	32	15	24	13
8	6	<1	48	28	43	26
16	12	<1	91	55	78	51
20	15	<1	114	73	98	68

On the basis of the developed IP core have been established 4-port stand-alone router and the router which are built into the system-on-chip based on the LEON3 [10]. Microsemi A3PE1500 and Microsemi A3PE3000 of FPGA were used, respectively. The maximum speed of the network that can be created on the basis of these devices is 200 Mbps. After remove and restore a power the router became fully operational in less than 1 ms.

## 6. Conclusion

This paper presents a priority group adaptive routing algorithm, which allows more flexibility to manage the routing process. It is designed for transmission of SpaceWire packets over a redundant network. The proposed solution is to manage the ports of the router via using and configuring of priorities tables. The solution allows to reserve the channels, switching to the backup channels and sending packets on channels with higher priority. Furthermore, is proposed a method for rapid restore functionality the router after power off using save the routing table and the router configuration in an external non-volatile memory.

The proposed solutions was used to create the router IP-core, and then tested in the FPGA when were creating 4-port stand-alone router and router built into the system-on-chip. The results illustrate the realizability and rationality of the proposed approach.

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