Upgrade of Ethernet-SpaceWire Protocol

Alexey Vinogradov, Evgeni Yablokov, Valeria Yachnaya
Saint-Petersburg State University of Aerospace Instrumentation
Saint Petersburg, Russia
alexey.vinogradov@guap.ru, evgeny.yablokov@guap.ru, valeria.yachnaya@guap.ru

Abstract—**This article is primarily concerned with an Ethernet-SpaceWire protocol upgrade. The protocol receives new capabilities due to renewal. The comparison of the characteristics of the old and new version of the protocol is also presented in the article.**

INTRODUCTION

SpaceWire network provides high-speed transfer between nodes. Nodes in the network can exchange information with high effeciency due to low delay and high data-rates. The ability of the priority data exchange and the opportunity of more priority characters to be embedded inside data packets allows to implement low latency high priority transfers.

In accordance with [1], the main SpaceWire disadvantage is deploying a data-strobe encoding (D/S encoding) scheme at the physical layer. Because of this encoding the maximum data rate in SpaceWire reaches 400 Mbit/s while the recommended SpaceWire cable length is 10 m and contains four twisted pairs (acceptable weight: 80 g/m). Despite all the advantages of D/S encoding, its main disadvantage is the use of 4 twisted pairs for transmission, which seriously limits the use of this technology in space (due to mass). In addition, D/S encoding makes it impossible to increase speed while increasing transmission distance [2]. Solving these limitations, a data transmission standard that improves the SpaceWire standard was developed. It is called SpaceFibre.

SpaceFibre [3] is a high-speed serial data-link designed for on-board space equipment. SpaceFibre allows to transfer data via both electrical and fibre-optic cables and supports data-rates from 1 Gbit/s to 5 Gbit/s. It is directed to complement the capabilities of the widely used SpaceWire on-board networking standard by improving the data rate by a factor of 10, reducing the cable mass and providing galvanic isolation capabilities. Multi-laning improves the data-rate further to well over 20 Gbits/s [4].

The Ethernet-SpaceWire protocol is used to transfer SpaceWire packets over an Ethernet network [1], but there are required improvements to transfer packets of other protocols. It was decided to design SpaceFibre network data transfer mechanism for further protocol development. Unlike the SpaceWire network, SpaceFibre has virtual channels [5], and using an old version of the protocol with new frame types over a new network will lead to large delays in a data transmission over multiple channels simultaneously [4]. The purpose of this article is to design a new version of the Ethernet-SpaceWire protocol called Ethernet-SpaceFibre. The new version of the protocol should allow to transfer control characters and data over virtual channels more efficiently than the old version of the protocol can offer.

Summing up, it's fair to say that SpaceFibre is the successor of the SpaceWire protocol. It has increased bandwidth, supports virtual channels, delivery guarantee and other advantages designed to expand SpaceWire protocol usage. Using 8b/10b encoding instead of D/S encoding at the physical layer allowed to increase speed and reduce hardware costs of transmitting devices.

II. OVERVIEW OF THE OLD ETHERNET-SPACEWIRE VERSION

The Ethernet-SpaceWire protocol was designed to transfer SpaceWire packets placed inside the Ethernet frames. This protocol supports two transfer modes — a mode with credit confirmation and a mode without credit confirmation.

In the mode without credit confirmation it is assumed that data have enough time to be transmitted before the receiving buffer is full. In the case of the mode with credit confirmation, receiving side informs the transceiving side about the amount of free memory. Fig. 1 shows Ethernet-SpaceWire protocol frame format. Each frame contains information on type of transmitting data, the number and size of the frame, credit and the transmitting data itself.

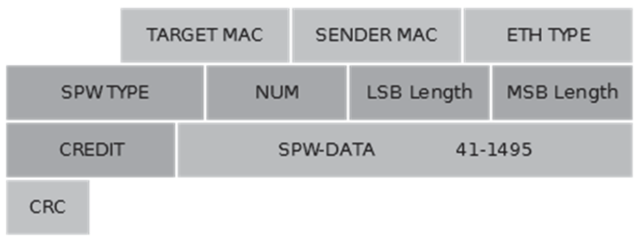

Fig. 1. Ethernet-SpaceWire frame

There are 7 types of frame defined in this protocol for data transfer. As the protocol in question is being used in the Ethernet-SpaceWire hardware bridge, it uses additional service frames that are applied to collect statistics and to configure the bridge. All the types and their descriptions are specified in Table I.

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TABLE I. ETHERNET-SPACEWIRE FRAME TYPES

Type	Meaning	Description
00h	MOF	Transmission of an intermediate (mesne) frame that contains a part of the SpW packet
Type	Meaning	Description
01h	FEOF	Transmission of an entire SpW packet that ends with a normal end of packet marker (EOP)
02h	FEEF	Transmission of an entire SpW packet that ends with an error end of packet marker (EEP)
03h	SOF	Transmission of the start of the SpW packet
04h	EOF	Transmission of an end frame of the SpW packet that ends with a normal end of packet marker EOP
05h	EEF	Transmission of an end frame of the SpW packet that ends with an error end of packet marker EEP
06h	CCode	Transmission of a frame containing one or more control codes
07h		Transmission error
08h		Statistics
9h-FEh		Reserved
FFh		Configurational frame

The old version of the protocol does not allow to use all the features of the SpaceFibre protocol, which shares many of the characteristics of the SpaceWire protocol [6]. As a result of studies [7][8] of the Ethernet-SpaceWire bandwidth, it was found that the protocol provides not so good characteristics when transferring small packets. In order to solve that problem, it makes sense to design a new version of the protocol, which shall use the channel more effectively.

III. SpaceFibre protocol overview

Following types of transmitting data are presented in the SpaceFibre protocol [9]:

1) *TimeCode:* disturbed interrupt codes, analogous to SpaceWire codes.

2) *BroadCast:* broadcast packets.

3) *Data:* data packets, containing a virtual channel number.

Let us take a closer look at data packets and broadcast packets [10].

Fig. 2 shows the SpaceFibre data frame format. It starts with the Comma — K28.7 or K28.5 control symbol, followed by the start-of-data-frame word (SDF) and the field that contains the number of virtual channel (VC), which specifies, which virtual channel sends data and which virtual channel should receive this data [11]. Each frame contains from 1 to 64 data words, each of which holds 4 SpaceFibre symbols. The next field is the end-of-data-frame word (EDF). The data frame ends with the SEQ_NUM field that specifies the sequence number of the current frame and a 16-bit field containing Cyclic Redundancy Code (CRC) that covers SDF, frame data and the EDF field.

0 7	8 15	16 23	24 31
COMMA	SDF	VC	RESERVED
DATA 1 LS	DATA 1	DATA 1	DATA 1 MS
DATA 2 LS	DATA 2	DATA 2	DATA 2 MS
...	...	...	...
DATA N LS	DATA N	DATA N	DATA N MS
EDF	SEQ_NUM	CRC_LS	CRC_MS

Fig. 2. SpaceFibre data frame

0 7	8 15	16 23	24 31
COMMA	SBF	BC	B_SEQ#/B_TYPE
DATA 1 MS	DATA 1	DATA 1	DATA 1 MS
DATA 2 LS	DATA 2	DATA 2	DATA 2 MS
EBF	RSVD/LATE	SEQ_NUM	CRC

Fig. 3. SpaceFibre broadcast frame

Fig. 3 shows a SpaceFibre broadcast frame format. The broadcast frame as well as the data frame starts with the Comma followed by the start-of-broadcast-frame word (SBF). The BC and SBF fields describe a broadcast channel, which sends or receives a broadcast frame. The following B_SEQ#/B_TYPE field consists of two parts: a 3-bit value which identifies the sequence number of the broadcast frame (B_SEQ#), contained in bits 7:5, and a 5-bit field which specifies the broadcast frame type (B_TYPE), contained in bits 4:0. The next are data fields followed by the RSVD/LATE field, which consists of two parts: a 7-bit reserved field (RSVD) and a 1-bit LATE flag, which is contained in the least significant bit position of the RSVD/LATE filed. The end of the broadcast frame specifies a 8-bit Cyclic Redundancy Code (CRC) that covers SBF, broadcast frame data and the EBF field.

Fig. 4. SpaceFibre packet format

Fig. 4 shows the SpaceFibre packet format. It consists of a destination address, transmitting data and an end of packet (EOP) or an error end of packet (EEP) marker. The destination address consists of zero or more data characters that specifies the path to the destination node or its logical address. The following EOP or EEP marker data character is a character of the next packet. The packet is terminated by an EEP marker in case of an error, which occurrence led to the loss of some of the data in the packet [12].

The SpaceFibre network can comprise up to 256 virtual channels. Each of this virtual channel has its own input and output buffer. The SpaceFibre packets can be of any length. In

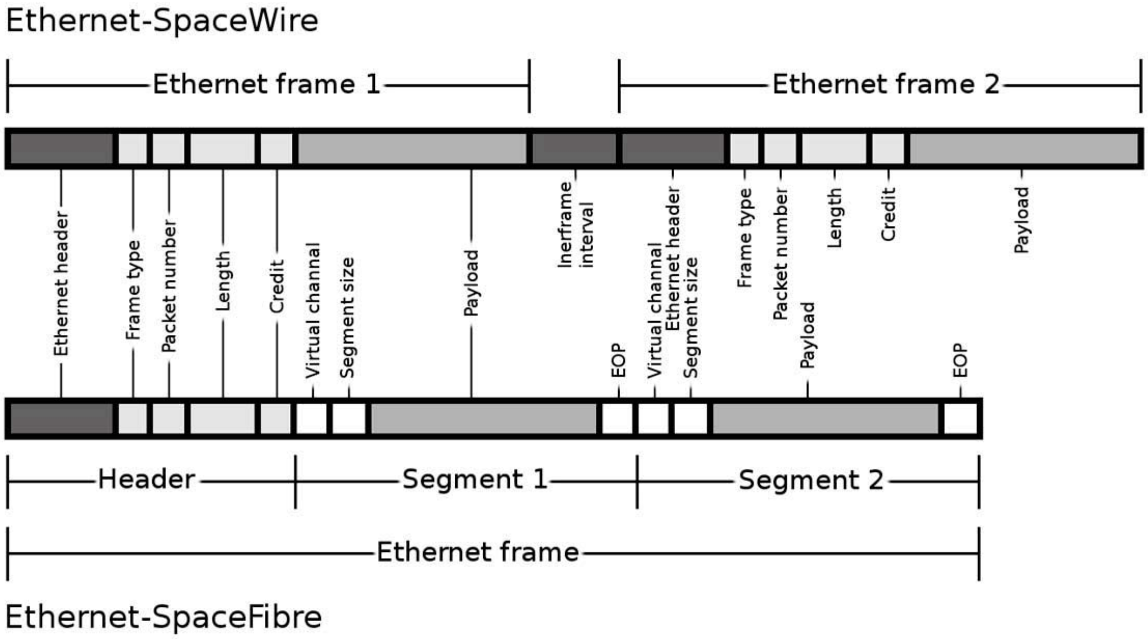

Fig. 8. Protocol comparison

case the packet's length exceeds the size of the virtual channel's output buffer and the packet cannot be written in the buffer entirely, it should be written by part just as free space for the next portion of data appears.

IV. Description of the new version of the Protocol

SpaceFibre protocol tries to solve the problems of SpceWire protocol, additionally adding new features for diffferent which are used for implementation of other protocols [13][14]. But the main problem lies in connection the SpaceWibre network to old, but widespread Ethernet networks.

The new version of the Ethernet-SpaceWire protocol — Ethernet-SpaceFibre — provides new frame types and new headers, solving the above problem. Transmitted data divided into segments with a maximum payload size of 1020 bytes. Each segment starts with 1 byte header, which indicates segment type, and the second byte specifies the size of transmitted data segment per 1 virtual channel (255 bytes in one segment from each of 4 channels). It is possible to transfer up to 4 virtual channels and blocks up to 8 disturbed interrupt codes or a broadcast packet simultaneously.

Fig. 5 shows the structure of the data segment.

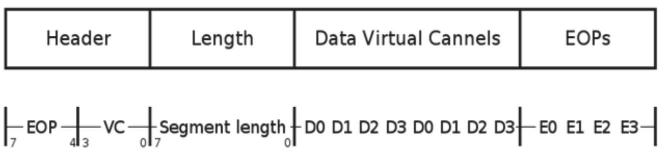

Fig. 5. Data segment structure

A first byte, Header, consists of two fields indicating used virtual channels and virtual channels that are terminating in the current data segment. The next byte, Length, indicates a data length per 1 virtual channel. The Data Virtual Cannels byte contains an alternating virtual channel data in order from 0 to 3.

The unused channel is skipped. The EOP field can be either an error end of packet EEP (0x01) or a normal end of packet EOP (0x00). The end-of-packet character is processed by the protocol as a normal data character, so it also shall be counted in the length of transmitting data field. If the virtual channel does not terminate in the current segment the normal data character is used instead of an end-of-packet character. The order of the end-of-packet characters in the segment is the same as for data characters. While transmitting normal data, it is impossible for the same channel to be unused an to be terminated in the current segment at the same time, so such a state in the Header field is used to specify other types of data in the transmitting segment. To transmit disturbed interrupt codes the binary value "1000" shall be written in the VC filed of the header and the EOP field shall begin with "0". The structure of the described above segment is shown in Fig. 6. A 3-bytes field is allocated to encode the number of disturbed interrupt codes transmitted at a time, which allows to send up to 8 characters.

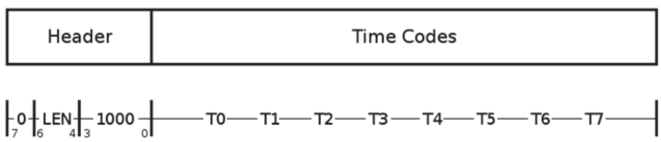

Fig. 6. "Time Code" segment structure

The structure shown in Fig. 7 is used to transfer broadcast packets. There is no need to allocate a special filed to specify the length of the data segment as the packets of this type shall always have the same length.

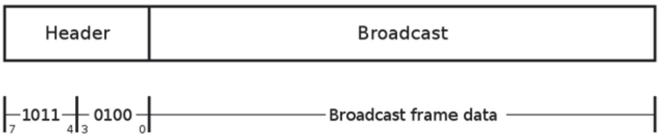

Fig. 7. Broadcast segment structure

In this figure the virtual channel field of the Header contains binary value "0100", and the end-of-virtual-channel field contains "1011".

Fig. 8 shows a comparison of the two protocols. The old one is the Ethernet-SpaceWire [15] and the new one — Ethernet-SpaceFibre, which extends the old version of the protocol.

The Header fields have not changed since the first version of the protocol, however the type of frame shall be specified as an Ethernet-SpaceFibre now and the described above fields shall follow the Header. The Length of frame field specifies the total size of the transmitting data segments along with control information. The purpose of the Credit field has not changed. The next are data segments. In case of transmission of two SpaceFibre packets using the old version of the protocol two Ethernet frames are required [16], with each frame containing a large amount of service information and, moreover, there is an inter-frame interval in that way. However, using the new version of the protocol requires only one Ethernet frame, because both packets would be packed into it.

Fig. 9 below shows an example of the transmission of three packets and one Time code over the three virtual channels.

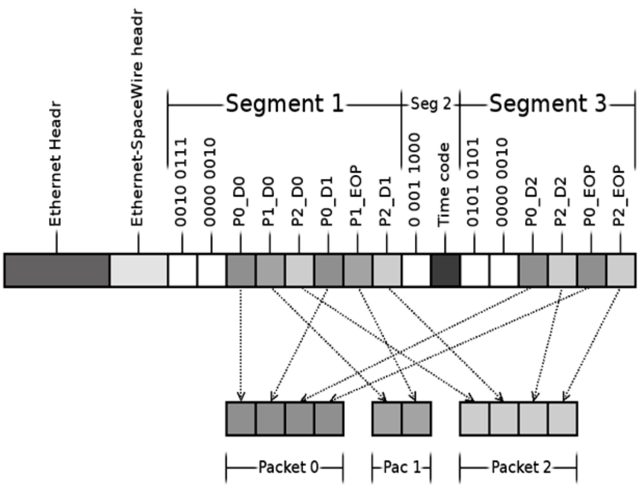

Fig. 9. Transmission of three packets and one Time Code

Such a transmission requires three segments. The first and third ones shall comprise the transmitting data, and the second one is used to transfer the disturbed interrupt codes (Time code).

The first segment involves three virtual channels at the same time, besides one of them is terminating in this segment. This information is described in the first byte of the Header field, which contains the binary value "0010 0111". The most significant tetrad of this byte is the EOP field and the least significant tetrad specifies virtual channels. The second byte of the Header contains value 2. This indicates that the length of the data segment shall be 5 bytes while 3 channels are used, that is the zero and second channels shall transmit 2 bytes each, and the first one shall transmit 1 byte and an end of packet character.

The first byte of the second segment contains the binary value "0 001 1000". It indicates that Segment 2 is used to transmit one-byte disturbed interrupt code. There is no second byte in the Header field of this segment in contrast to the previous case.

The Header of the Segment 3 is similar to the one in the Segment 1, but it transfers only 2 one-byte channels and both of them are terminating in this segment.

V. Comparison of the protocols

To analyze the efficiency of the new version of the protocol, a mathematical model which compares both versions was designed.

Let us take a detailed look at the Ethernet-SpaceWire protocol model.

To calculate the amount of transmitting data it is enough to simply multiply two components: the packet size D and the number of transmitting packets P. In case the Ethernet frame is used, the packet size D shall be greater than or equal to forty-six bytes.

$$D_{SpW} = D \cdot P, D \geq 46$$

Formula 2 is used to calculate the total amount of transmitted information, including the service information and the inter-frame interval.

$$D_{SpW-full} = H(P \cdot VC + \left\lfloor \frac{D_{SpW}}{1495} \right\rfloor + D_{SpW}$$

H – size of the Ethernet service information, inter-frame interval and the Ethernet-SpaceWire protocol service information.

P — number of transmitting packets.

VC — number of virtual channels in the model.

Next, we will look at the Ethernet-SpaceFibre protocol model.

The main difference between the Eth-SpFi model and the previous one is that each new packet adds 3 bytes of service information, and, furthermore, 3 bytes are added for every 255 bytes of the packet.

$$D_{SpFi} = D \cdot P \cdot VC + 3 \cdot P + \left\lfloor \frac{P \cdot D}{255} \right\rfloor \cdot 2$$

The following formula is used to calculate the total amount of transmitted data:

$$D_{SpW-full} = \left\lfloor \frac{D_{SpW}}{1495} \right\rfloor H + D_{SpFi}, D \geq 46$$

H — size of the service information, which is the same as for the previous model, since the Eth-SpFi is an extension of the Eth-SpW.

VI. Results

The simulations have been carried out in several ways. Initially, the model was launched in the one packet transmission and one virtual channel mode, then the number of packets and virtual channels had been changing.

The graph in Fig. 10 shows the difference between the Ethernet-SpaceFibre and Ethernet-SpaceWire protocols in the total amount of transmitting data, which depends on the size of the packet. The model has been running in the one packet transmission and one virtual channel mode. The size of the transmitting packet is on the X-axis, and the difference between the Eth-SpW and Eth-SpFi protocols in the total amount of the transmitted data is on the Y-axis.

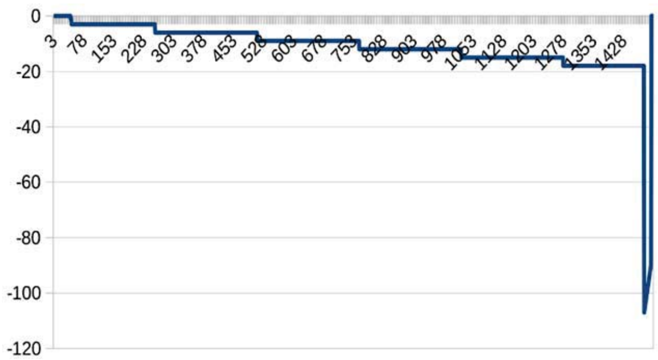

Fig. 10. Difference in the amount of service information in 1 channel with 1 packet of up to 1500 bytes

The above graph was produced for the packets, whose size ranges from 1 to 1500 bytes. Both protocols show similar results while the size of the packet is under 43 bytes, and then 3 bytes of service information are added for every 255 bytes of the packet in the Eth-SpFi protocol. A sharp dip is seen in the graph when the packet size approaches the value of about 1500 bytes. It indicates that the Eth-SpFi protocol reaches the maximum Ethernet frame size much faster. The graph below was produced for the same model, but the size of the packet is up to 4500 bytes now.

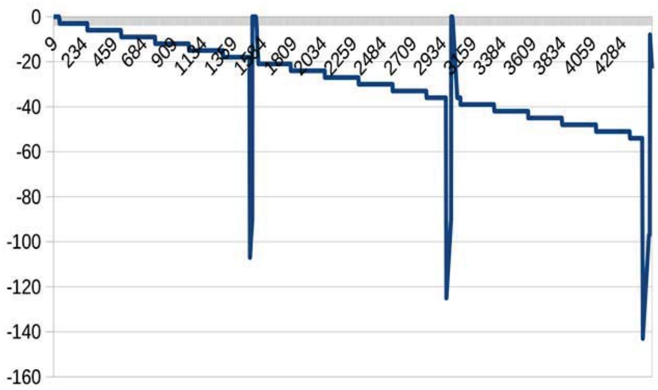

Fig 11. Difference in the amount of service information in 1 channel with 1 packet of up to 4500 bytes

The graph shows that the more the size of the packet is, the more is the amount of service information. This could lead to the conclusion that applying the developed protocol to transmit one packet using single virtual channel does not appear to provide any advantage, or even the opposite.

Fig. 12 shows that using 4 virtual channels benefits for the Ethernet-SpaceFibre protocol in about 30 bytes for the 1500-byte packets.

Increasing the number of bytes in packets up to 4500 will produce the results shown on the graph in Fig. 13. Since the new protocol allows to transmit all the 4 virtual channels at the same time as it packs them into a single frame, there is a drop in efficiency at the points where the size of the frame starts to exceed.

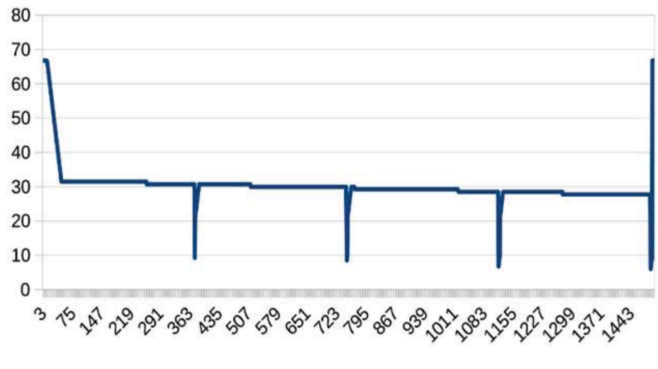

Fig. 12. Difference in the amount of service information in 4 channels with 1 packet of up to 1500 bytes

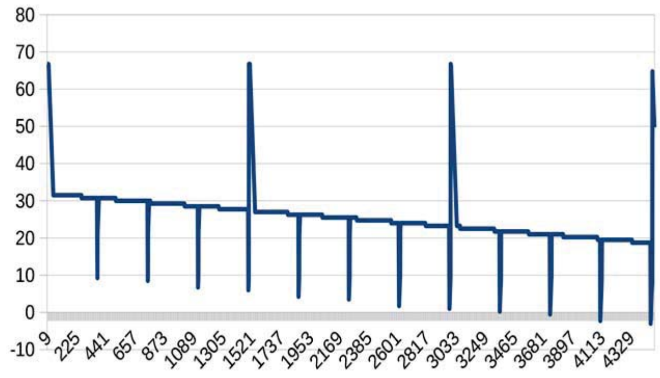

Fig. 13. Difference in the amount of service information in 4 channels with 1 packet of up to 4500 bytes

At this moment, small frames which contain more service information rather than payload appear in the network. The old version of the protocol cannot pack four channels into a single frame, so they are transmitted in the different ones. When the frame size exceeds, the number of small frames per number of virtual channels in the network increases. The points that indicate the improvements in performance of the new protocol correspond this occasion.

The new protocol provides much more efficient performance in the case of 4 virtual channels in comparison with the usage of a single channel.

Let us take a look at the models that transfer 10 packets instead of one. Only one virtual channel is used.

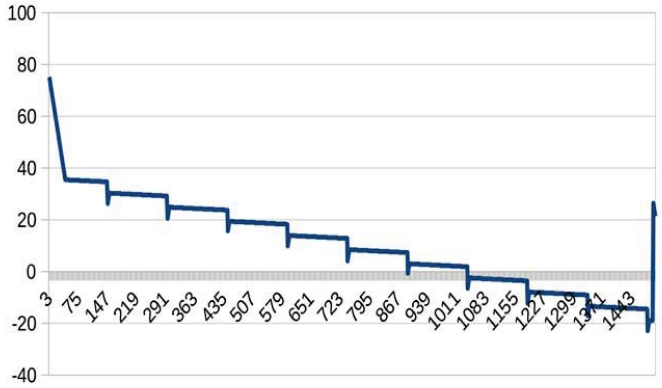

Fig. 14. Difference in the amount of service information in 1 channel with packets of up to 1500 bytes

The graph in Fig. 14 is analogous to the one shown in Fig. 10, but the number of transmitting packets rose to 10. This graph indicates that the protocol shows a good performance on packets of up to 1036 bytes size. This is related to the fact that the protocol allows to pack several packets into a single Ethernet frame.

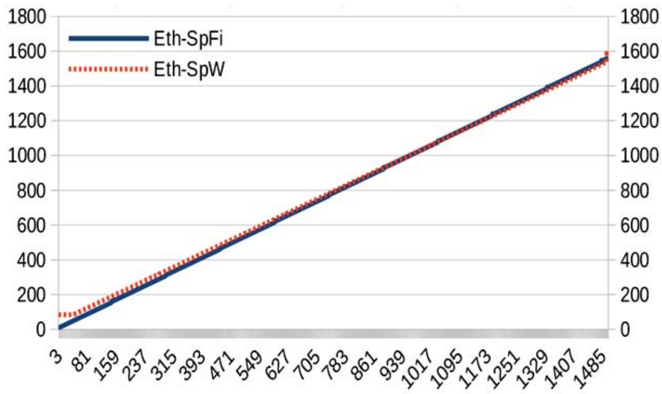

Fig. 14. Total amount of transmitted data in 4 channels with packets of up to 1500 bytes

The graph in Fig. 15 shows the ratio of the packet size, which is on X-axis, to the total amount of all transmitted bytes, which is on Y-axis.

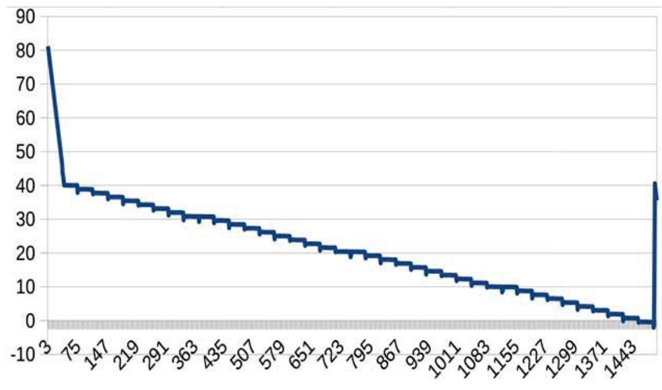

Fig. 16. Difference in the amount of service information in 4 channels with packets of up to 1500 bytes

Increasing the number of virtual channels up to 4 will produce the results shown on the graph in Fig. 16, and Fig. 17 shows graph of the model with the same parameters, but the packet size rose to 4500 bytes.

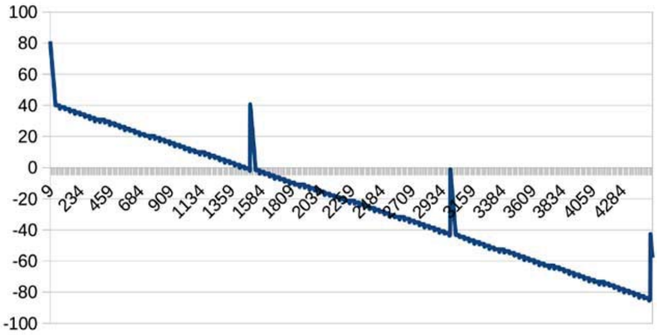

Fig. 17. Difference in the amount of service information in 4 channels with packets of up to 4500 bytes

VII. Conclusion

The new protocol is effective in using 4 virtual channels only in the case of the packets whose size is up to one frame.

The developed protocol certainly benefits in transferring small packets, and since it is an extension of the old version of the Ethernet-SpaceWire protocol, there is an opportunity to utilize both protocols in the same device at the same time, which would allow to transfer data much more efficiently.

During the research and development a more efficient protocol that complements and extends the capabilities of the Ethernet-SpaceWire protocol was designed. The resulting protocol allows to transmit small packets more efficiently using four virtual channels simultaneously.

Acknowledgment

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