# Research and Analysis of Flow Control Mechanism for Transport Protocols of the SpaceWire Onboard Networks

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***Abstract*—The paper provides the analysis of the existing solutions for the flow control mechanisms of the well-known industrial protocols (Infiniband, Fibre Channel, PCI Express, USB 3.1), protocols for mobile communications (UniPro), protocols for global networks (TCP/IP) and onboard networks (SpaceWire, GigaSpaceWire, SpaceFibre, JRDDP, SpaceWire-R, RapidIO, STP). Current analysis resulted in the Flow Control mechanism that was proposed during the development of the new transport protocol STP-ISS for the onboard networks.**

## I. Introduction

Flow control plays an important role in onboard systems of the space vehicles. Each node of the onboard network should have valid information on the status of other network devices through the information exchange. Therefore, we need a special mechanism to control the data flow and to guarantee reliable and timely data transfer between the nodes of the onboard network.

The flow control mechanism helps to synchronize the data transmission rate of the transmitting and receiving sides, i.e. to give ability to transmit the data to the receiving side in accordance with the free buffer space in the receiver [1].

During the development of the second revision of the STP-ISS [2] protocol for onboard networks, we got the requirement to have possibility of the large-sized packets transfer via the specific transport connection. So in the STP-ISS rev.2 protocol [3] we implemented a transport connection mechanism for transmission of packets, which have the size up to 64 KB. To avoid the data loss during the transmission we provided the flow control mechanism. For this purpose we analyzed the flow control mechanisms of the well-known existing industrial protocols (Infiniband [4], Fibre Channel [5], PCI Express [6], USB 3.1 [7]), protocols for mobile communications (UniPro [8]), protocols for global networks (TCP/IP [1]) and onboard networks (SpaceWire [9], GigaSpaceWire [10], SpaceFibre [11], JRDDP [12], SpaceWire-R [13], RapidIO [14],STP [15]). The short overview of this analysis is represented in the next chapter of the paper.

## II. General Description of the Considered Protocols

### *A. Infiniband*

InfiniBand is high performance architecture designed for exchange of the data between the servers, communication systems and storage devices at high speed (up to 25.8 gigabits per second). It is used for both internal and external system connections.

Flow control is implemented in the data link layer and it is done by sending of the number of credits in special flow control packets. To transmit the data with the flow control the Virtual Link should be established between the receiver and the transmitter. Flow control packets could be sent through a virtual line during the connection establishment (command packets) and after the successful connection establishment (data packets).

These packets have a field containing information on the number of packets that was transmitted since the initialization and a field with the credit limit in the receiver. To transmit the data the transmitter should know the information on the amount of free space in the receiving buffer. The transmitter sends a flow control packet with information on the number of packets that was sent since the initialization phase. When receiver gets a packet, it stores the number of packets value. Then it forms the credit limit field for the response control packet. The value of this field is based on the amount of free space in the buffer and the amount of the saved data modulo 4096. The final packet is passed to the transmitter, so it could start the data transmission. The transmitter can send data packets if the credit limit field value that it got in the last control packet minus the number of transmitted packets since the initialization modulo 4096 is less than 2048. If this condition is not met, the transfer is not possible. In this case the value of the credits limit field should be updated again by sending another flow control packet.

At the transport layer Infiniband standard has end-to-end flow control mechanism. After the connection establishment the transmitter requests available credits from the receiver on the transport layer. Credits are generated in the receiving queue of the receiver and is used in the transmitting queue of the

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transmitter. After generating, the credits should be encoded and sent from the receiver to the transmitter as a confirmation message.

Request of the credits from the receiver is performed during the read commands, write commands, resynchronization commands and acknowledgements. The available credits information is stored in a special field of the message header.

*B. PCI Express*

PCI Express is a computer bus, which is represented by a set of consecutive channels with the point-to-point connection on a physical layer. PCI Express uses a software model of PCI bus and high-performance protocol based on serial transmission of data.

PCI Express uses the credit-based flow control mechanism at the network layer. This mechanism could be used after a virtual channel establishment between two devices. Credit-based flow control guarantees that packets would not be dropped off due to the receive buffer overflow. Flow control information is transmitted by means of the data link layer packets.

The flow control packets containing the information about the receiving device should be sent to the transmitting device, so transmitter can send packets to the receiver, if it has enough buffer space to receive a packet.

The transmitter stores the current information on the number credits at the receiver in a special available credits counter. After the successful transmission of the packet, the transmitter reduces the available credits counter value. If the available credits value is less than the size of a transmitting packet, the transmission should be stopped, until the transmitter will not receive the new information on the current available space of the receiver. After the receiving and processing of the packet the receiver releases the receiving buffer, updates the available buffer space information and transmits new flow control packet to the transmission side.

*C. USB 3.1*

USB (Universal Serial Bus) is a serial data transmission interface for medium-speed and low-speed devices. The main advantage of USB 3.1 is the data transmission speed up to 10 GB/s.

USB 3.1 uses end-to-end flow control at the network layer. This flow control mechanism uses special transaction packets: ACK, NRDY (NOT READY), ERDY (ENDPOINT READY), etc. Before the data exchange begins, the transmitter (host) sends to the receiver (device) an ACK packet with sequence indicator SEQ and a number of packets NumP. NumP and SEQ determine the identifier and the number of packets to identify the data transmission flow. After that, the device can start to send packets to the host; however, the host can receive only such number of packets with SEQ, which was indicated in the ACK packet. If the expected packet with SEQ is lost or the number of packets differ from the SEQ, the transmitter re-sends the ACK with the required number of packets and a special resend flag. At the receiver side an unacknowledged packet should be re-sent. If the current packet is the last packet that should be sent, then it is marked with a special flag. The transmission will be continued, if the receiver will send ERDY packet and transmitter will send an ACK packet again. If the transmitter expects the data transmission from the receiver, and the receiver is not ready, the receiver sends NRDY packet to the transmitting side. This mechanism is used in USB 3.1 protocol to not occupy the channel with the large number of packets. NRDY packet informs the transmitting side that the receiver is not ready to transmit data. The transmitter does not transmit packets and waits ERDY packet, which indicates that the receiver has data to send or it is ready for sending, so the transmitter needs to send ACK.

*D. Fibre Channel*

Fibre Channel is protocol stack for implementation of Storage Area Networks (SAN), which provides high-speed data transfer.

Flow control in Fibre Channel Protocol is implemented in two mechanisms: “buffer-to-buffer” and “end-to-end” management. The choice of the particular mechanism is based on the class of service. Buffer-to-buffer flow control mechanism is used for the data exchange between two ports. All the frames incoming to the input port should be stored in special buffers. The number of these buffers depends on the physical characteristics of the port. One buffer corresponds to one credit. Each port has two credit counters: transmitted credits counter and received credits counter. In the sending port credits counter value should be decremented after the sending of each frame. If the counter value equals to zero, then further transmission is not possible. If the receiving port gets an acknowledgment, the value of the transmitted credits counter shall be incremented by one.When the receiving port got the data, the frame is stored in the RX buffer, and the received credits counter is decremented. When the frame will be processed and transmitted from the buffer, the received credits counter will be incremented and an acknowledgement will be sent to the transmission port.

The end-to-end flow control mechanism is used for the data exchange between the end nodes. Each node has two counters: received credits counter and transmitted credits counter. The transmitted credits counter determines the maximum number of frames that the transmitter can send to the receiver without receiving of acknowledgement. The received credits counter determines the number of credits that the receiver can receive without sending an acknowledgement to the transmitter. The counters of the end-to-end flow control mechanism are applied only to the data frames.

*E. TCP/IP*

TCP/IP is an industrial protocol stack designed for global networks.

This family of network protocols is widely used in most operating systems. TCP/IP defines the main communication language for the Internet environment. The key protocols are IP (Internet Protocol) and TCP (Transmission Control Protocol).

In order to speed-up and optimize the transfer of large amounts of data the TCP protocol defines the flow control mechanism called "sliding window", which allows the sender to send the next segment without waiting for the confirmation from the destination point of the preceding segment.

TCP protocol generates acknowledgments not for each successfully received packet, but for all data from the beginning of the transmission and till the some serial number ACK SN (Acknowledge Sequence Number). To confirm the successful reception of the first N bytes receiver sends ACK SN = N+1, which acknowledges receipt of the data from (SN-N+1) till the (ACK SN-1). When receiver sends the ACK SN, it also declares the sliding window size for send the next transmitting data. This means that the sender can send data with sequence numbers from the current ACK SN till the ACK SN+window size-1, without waiting for acknowledgment from the recipient. The receiver could dynamically change the window size. The size of the window is selected such a way that the acknowledgment has to be successfully transmitted and transmission does not stop. For temporary stop of the transmission, a null window could be defined. However, even in this case, segments with one data octet would be periodically sent. This is done to ensure that the sender knows that the receiver declared the newly announced non-zero window again, because the receiver should acknowledge the receiving of the "trial" segments, and these acknowledgements will contain the current size of the window.

### *F. UniPro*

UniPro (or Unified Protocol) is a high-speed interface technology for interconnecting integrated circuits in mobile and mobile-influenced electronics such as mobile phones, laptops, digital cameras and multimedia devices.

The Data Link layer of the UniPro protocol uses credit-based flow control mechanism, in which the receiver transmits information on available credits via special frames. The data link layer has several types of control frames, which are used for flow control and error handling. These control frames called AFC frames (acknowledgment and flow control) and NAC frames (signaling the presence of errors and starting of retransmission). These frames do not contain application data. Three bits in the frame header identify it. When transmitter sends the data frames, the receiver sends the AFC response frames informing the successful reception of the data and available buffer space at the receiver. UniPro also supports the multiple data frames confirmation by sending a single AFC frame. NAC frames are sent from the transmitter to the receiver, if receiving frames are corrupted.

At the transport layer UniPro protocol uses end-to-end flow control, which is performed by sending information on the free space in the receiver buffer. During the establishment of the connection between two nodes, both sides define the transmission direction and the value of the control token in bytes, which would be used to transmit receiver's buffer free space. Each receiver has a counter of credits that are available for sending, and each transmitter has a counter of free buffer space. After establishment of the connection the transmitter does not have information on the number of available credits. Therefore, after counting of free space the receiver starts to send messages with a control token to the transmitter until the counter value of available credits will not be less than the value of a control token. The transmitter, in turn, receives messages with tokens, the counter increments the available buffer space by an amount equal of e value of a control token value. The transmitter always counts the amount of data that could be sent. Once the size of the available buffer space counter is greater or equal to the size of the message to be sent, then the transmitter sends the message (per 272 bytes or less). After that, the number of transmitted bytes is subtracted from the available buffer space counter value. If the number of bytes available to send is not enough, then transmitter will wait to receive more credits from the receiver.

### *G. SpaceWire*

SpaceWire standard is intended for data transmission and information management of onboard equipment for aircraft and spacecraft. This standard uses a high-speed (2 - 400 Mbit / s) full-duplex links that meet high reliability requirements, independence from receiving and transmitting hardware and other aerospace requirements.

SpaceWire provides a unified communications infrastructure for data processing systems that enables interaction with sensors, signal processors, data processors, massive memory modules, subsystems hardware telemetry and other electronic equipment used on board of aircraft and spacecraft.

To protect the receiving host-system from buffer overflow and loss of data SpaceWire controls the data flow. It is done by credit based flow control. The transmitter is able to send symbols only if the receiving buffer in host-system on the other side of the connection has free space for them. Host-system informs that it has free buffer space for another 8 information characters by sending a request to the transmitter for sending of flow control symbols (FCT - Flow Control Token). This symbol, received by the destination node, gives an ability for transmitter to send eight information characters. If the receive buffer in a host-system allows to take more than eight information symbols, the transmitter may send multiple flow control symbols (each of them will allow the transfer of eight characters). For example, reception of four flow control symbols allow the transmitter to transmit 32 information symbols.

### *H. SpaceFibre*

SpaceFibre is a spacecraft standard that allows transferring data via fiber optic and copper cables and supports data rates up to 2 Gbit/s and 20 Gbit/s. SpaceFibre provides a mechanism to ensure the quality of service that can support guaranteed delivery, priority, guaranteed bandwidth and scheduling quality of service.

SpaceFibre link layer uses credit-based flow control mechanism. This mechanism is used for transferring data via virtual channels. The transmitter is allowed to send frames only if the reception buffer at the remote side of the channel has free space for these frames. The receiver indicates that it has free space for more than 256 N-Char characters. It sends a request for the transmitter to send FCTs (Flow Control Token). The transmitter has to keep track of all received FCT symbols.

When a certain virtual channel received FCT, FCT credit counter should be incremented by 256. When a particular virtual channel sends a data frame, the value of FCT credit counter should be decremented by the number of N-Char characters and FILLs, that was send in this frame. Transmitter is not allowed to send data frames if FCT credit counter value is less than 256. When a data frame ready for transmission, the size of the frame is compared with the value of the FCT counter. If FCT credit counter is greater or equal to the size of the data frame, then the frame is allowed to be sent. If the value of the FCT credit counter overflows, this FCT should be discarded. At the same time FCT credit counter should be set to its maximum value.

### *I. GigaSpaceWire*

The GigaSpaceWire protocol stack uses network and packet layers of SpaceWire and introduces new exchange, character, coding and PHY layers.

GigaSpaceWire provides functions of establishing and maintaining connections and flow control mechanisms. It detects and handles errors that occur during transmission over a link. It controls access to the transmission medium and aligns the frequency and code sequences, performs bit synchronization, serialization and de-serialization, as well as 8b10b encoding and decoding.

GigaSpaceWire flow control mechanism can operate in SpaceWire flow control mode and in GigaSpaceWire flow control mode.

The main difference between GigaSpaceWire flow control mode and SpaceWire flow control mode is in the number of information bits, which carry a flow control character FCT. In SpaceWire mode one FCT corresponds to 8 N-Chars while in GigaSpaceWire mode it corresponds to 32 characters. This is the only difference in two flow control modes of GigaSpaceWire.

### *J. JRDDP*

JRDDP is transport protocol for reliable data delivery for SpaceWire networks. It provides reliable services of data delivery to a multiple applications using the SpaceWire.

The size of the sliding window shall be as agreed between the transmitting and receiving transport end points after establishment of a transport connection (transport channel). The sliding window size must be a power of 2 and the maximum sliding window size shall be 256. The receive window range shall start with the sequence number of the next data packet expected to be delivered and end with sequence number equal to the start plus window size minus 1. The receive window shall be advanced by 1 upon receipt of a packet containing the next expected sequence number. If the receiver gets two packets with adjacent sequence number (not with the start of window number), then after the receiving of data packet the size of the window could be extended by the number of received adjacent packets plus one. Each successfully received and processed packet is confirmed by sending an acknowledgment (ACK) packet. Any packet received with detectable errors shall be discarded and not acknowledged. If a data packet is received with a sequence number that is not within the receive window, it shall be discarded and not acknowledged. A data packet which is received with a sequence number within the receive window that is a duplicate of a packet pending delivery to the host should be acknowledged, but discarded. In turn, the transmitter has its own transmit window. The transmit window start shall be set to 1 when a CONTROL packet's ACK is received. The size of this window should not exceed the size of the sliding window. The transmit window start shall be advanced by 1 when the ACK is received for the first sequence number in the transmit window.

### *K. SpaceWire-R*

SpaceWire-R is a protocol that provides onboard applications with reliable data transfer services over SpaceWire networks.

Flow control in SpaceWire-R Protocol is implemented in two mechanisms: "sliding window" and "modified sliding window". The sliding window shall be a range of k consecutive Sequence Numbers (modulo 256). The size of the sliding window (k) shall be less than or equal to 128. Until transport connection is active, the sliding window shall be set to the range from 1 to k inclusive. When the sliding window is from $n$ to $n+k-1$, it is advanced by 1 (that is, it becomes from $n+1$ to $n+k$) upon reception of the acknowledgement for the Data Packet with Sequence Number $n$. The acknowledgements for the Data Packets with consecutive Sequence Numbers $n+1$, ..., $n+p$ have already been received when the acknowledgement for the Data Packet with Sequence Number $n$ is received, the sliding window shall become $n+p+1$ to $n+p+k$. The first Data Packet transmitted after a connection established shall have Sequence Number 1. When the previously transmitted Data Packet had Sequence Number m, the next Data Packet to be transmitted shall have Sequence Number m+1. If m+1 is within the current sliding window, it shall be transmitted immediately. If not, its transmission shall be deferred until m+1 is included in the sliding window.

If modified sliding window flow control is used, the data transmission shall be modified as follows. When the Data Packet previously transmitted had Sequence Number $m$, the next Data Packet to be transmitted shall have Sequence Number $m+1$. If $m+1$ is less than or equal to the Maximum Acceptable Sequence Number (MASN = 256) contained in the most recent Ack or Flow Control Packet (used by the Receiver to inform the Transmitter of the maximum value of the Sequence Number it can accept (MASN)), it shall be transmitted immediately. If not, its transmission shall be deferred until $m+1$ becomes less than or equal to the MASN.

### *L. STP*

STP is transport protocol is designed for the simultaneous transmission of multiple streaming data flows in SpaceWire networks. STP protocol provides a transport connection between two nodes, where one side of the connection is the master and the other side is the slave. The initiator of the data exchange connection is the master device which manages a connection establishment, setting of its parameters and packet exchange.

STP also uses end-to-end flow control mechanism. The connection between the transmitter and the receiver is established by means of classic three-phase protocol. During the connection establishment, receiver gives credits to N packets, which could be received. If the receiver sends N = 0, that means that transmitter has an unlimited number of packets. When the connection is established, the receiver sends a command to start the transfer of data packets. Transfer packets the Transmitted sends the number of packets equal to the number of received credits. If the transmitter is allowed to transfer N packets, it should stop the transmission and wait for new credits from the receiver.

*M. RapidIO*

RapidIO is a high-performance packet-switched, interconnect technology. RapidIO supports messaging, read/write and cache coherency semantics. RapidIO fabrics guarantee in-order packet delivery, enabling power- and area-efficient protocol implementation in hardware. RapidIO can be used as a chip-to-chip, board-to-board, and chassis-to-chassis interconnect.

The Physical layer of the RapidIO protocol uses credit-based flow control mechanism. This mechanism has two operating modes: receiver-controlled and transmitter-controlled flow control.

Receiver-controlled flow control is the simplest and most basic method of flow control. In this method, the input side of a port controls the flow of packets from its link partner by accepting or rejecting (retrying) packets on a packet by packet basis. The receiving port provides no information to its link partner about the amount of buffer space it has available for packet reception. As a result, its link partner transmits packets with no a priori expectation as to whether a given packet will be accepted or rejected. This method is named receiver-controlled flow control because the receiver makes all of the decisions about how buffers in the receiver are allocated for packet reception.

In transmitter-controlled flow control, the receiving port provides information to its link partner about the amount of buffer space it has available for packet reception. With this information, the sending port can allocate the use of the receiving port's receive buffers according to the number and priority of packets that the sending port has waiting for transmission without concern that one or more of the packets shall be forced to retry. This method is named transmitter-controlled flow control because the transmitter makes almost all of the decisions about how the buffers in the receiver are allocated for packet reception.

TABLE I. COMPARISON OF THE CONSIDERED PROTOCOLS

| Protocols / Parameters | Infiniband | Fibre Channel | PCI Express | USB 3.1 | TCP/IP | UniPro | SpaceWire | SpaceFibre | GigaSpaceWi re | JRDDP | SpaceWire-R | RapidIO | STP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scope Of Application** | HPCN, CC | HPS, SAN | HPS, HSTDSI | PR | LAN, WAN | MSD | OE | OE | OE | SN | SN | OE | SN |
| **Layers OSI** | CL, TL | NL | NL | CNL | TL | CL, TL | CL | CL | CL | TL | TL | CL, NL | TL |
| **Credit-Based FC** | √ | - | √ | - | - | √ | √ | √ | √ | - | √ | √ | - |
| **End-To-End FC** | √ | √ | - | √ | - | - | - | - | - | - | - | √ | √ |
| **Buffer-To-Buffer FC** | - | √ | - | - | - | - | - | - | - | - | - | - | - |
| **Sliding Window FC** | - | - | - | - | √ | - | - | - | - | √ | √ | - | - |
| **Support Connection** | √ | √ | √ | √ | √ | √ | - | √ | - | √ | √ | √ | √ |
| **Unit Credit** | 1 byte | 1 data frame | 16 byte | packet id | 1 packet | 1 byte | 8 char symbols | 256 char symbols | 8 or 32 char symbols | packet id | packet id | 1 packet | packet id |
| **Max Data Size In Bytes** | 4096 | 2048 | 4096 | 1025 | 64K | 306 | no limit | 256 | no limit | 64K | no limit | 64K | 4G |

The table uses the following abbreviations: HPCN - high-performance computer networks; HPS - high-performance systems; CC - computing complexes; PR - peripherals; HSTDSI - high-speed transmission devices and storing information; SAN - Storage Area Network; LAN - local area network; WAN - Wide Area Network; OE - onboard equipment; MSD - mobile systems and devices; SN – SpaceWire networks; CL – channel layer; TL – transport layer; NL – network layer; CHL – channel-network layer; FC – flow control

At the Logical layer RapidIO protocol uses end-to-end flow control, which is performed by sending flow control messages between nodes. A FLOW_CONTROL message is used to regulate traffic and manage traffic congestion. There are three types of flow control behavior which can be specified. First, use the XON command to enable data traffic. Second, use the XOFF command to suspend data traffic. In the case that data traffic is suspended, RTS message can be used to inform the stream owner (data receiver) that data is available to be sent. For example: the transmitter has data to send. It sends a FLOW

CONTROL message with RTS, which signals to receiver that there is data to receive. The receiver sends FLOW CONTROL XON command to transmitter and preparing to receive data from the transmitter. Then transmitter transmits data. After receiving of the data the receiver sends a FLOW CONTROL XOFF command to transmitter to finish the reception.

## III. COMPARISON OF THE CONSIDERED PROTOCOLS

Current section provides a comparison of all the considered protocols, we compare the protocols by different parameters: application of the protocols, flow control types, characteristics of flow control, the layer of application, etc. The results of the comparison are shown in Table I.

Flow control mechanisms can be divided into two main groups:

- flow control with feedback (the receiver allows the transmitter to continue data transmission or report the receiver status);
- limited flow control (the protocol limits the transmitter's rate, no acknowledgements from the receiver) [8].

All the overviewed protocols use the scheme with feedback, and all flow control mechanisms (from the link layer to the transport layer) based on the credit exchange mechanism, as the most effective one. This mechanism has the following main features:

- buffering at the transmitting and the receiving side;
- credits are equal to bytes of data;
- the size of the transmitted data up to 4 KB;
- credit information is updated by acknowledgments.

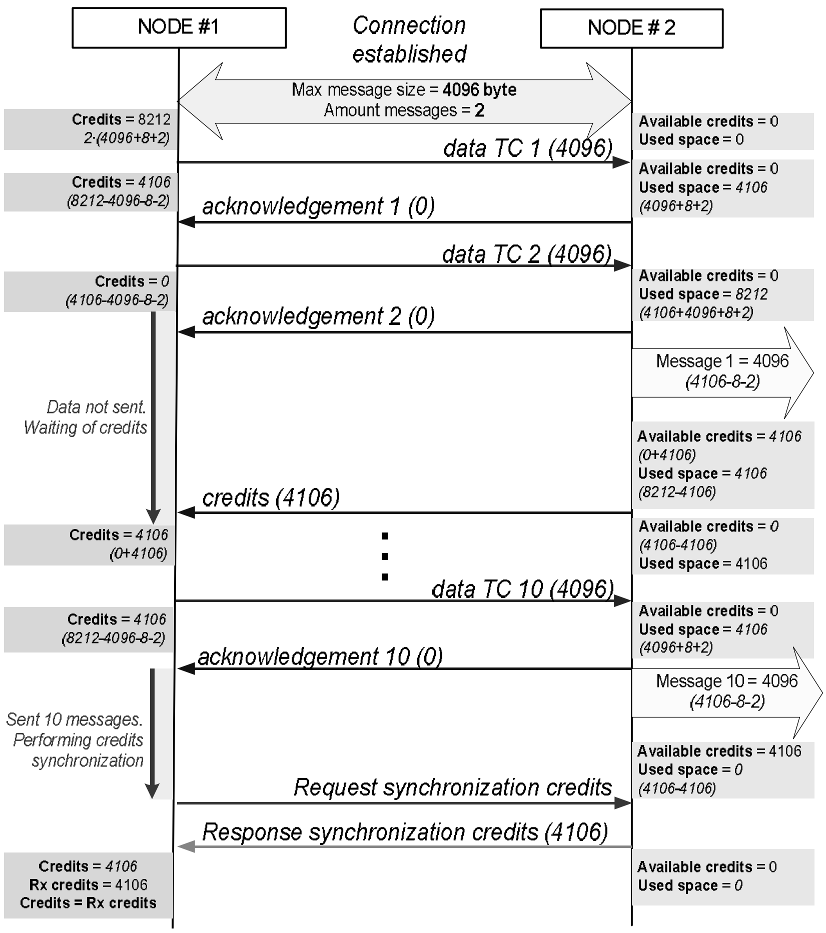


Fig. 1. An example of STP-ISS flow control mechanism

## IV. DEVELOPED FLOW CONTROL MECHANISM FOR STP-ISS

Taking into account the analysis of flow control mechanisms and requirements for the transport protocol that we got from space industry [3], we proposed a solution for the flow control mechanism of STP-ISS rev.2 protocol, which is developed for the SpaceWire onboard networks.

The receiving buffer size in STP-ISS protocol could be very small (only for two packets) and it is necessary to count the number of transferred bytes, which could not be done by using of the "sliding window" mechanism. Therefore, we use end-to-end flow control mechanism. Using STP-ISS flow control mechanism receiver should send the information on the amount of free space in the receive buffer. An example of this mechanism is shown in Fig. 1. This mechanism could be used only for STP-ISS transport connections with Guaranteed quality of service. The receiving node during the transport connection establishment should reserve the requested buffer space and count it. Each transport connection has a counter of free credits and counter of space used in the buffer. Information on free space in the buffer should be sent in the acknowledgement packet. If the value of free space in the buffer changes after sending the acknowledgment (e.g., an application read data from the buffer), then the receiver sends an acknowledgment packet with a special flag that tells that it is not an acknowledgment packet, but just credits. The transmitting node gets the available credits information and calculates the amount of data that could be sent for each transport connection. The amount transmitted data should be equal to a reserved space in the receive buffer.

To avoid loss of credits information (in case of corruption of acknowledgement packet) STP-ISS uses credits synchronization mechanism. Synchronization of credits between the receiver and a transmitter should be carried out after each N packets are sent to the receiver. For this purpose transmitting node send the credit synchronization request. Receiver gets this packet and responds with the current value of credits counter. Then the transmitter checks if his credits number value is still valid. Currently, in STP-ISS rev.2 protocol specification the frequency of synchronization value N is set 10. But this parameter can vary depending on several different factors, such as packet generation rate, network bandwidth, bit error rate or data packet length. Therefore, the value of 10 packets should be clarified. To clarify it, it is necessary to analyze how often the synchronization packet should be transmitted.

## VII. Conclusion

In current paper, we analyzed the flow control mechanisms in existing industrial protocols and protocols for on-board networks. In addition, we presented a flow control mechanism of STP-ISS rev. 2 protocol, which has been developed depending on the results of the analysis.

All the overviewed protocols have many similar properties on different layers of the OSI model. It is buffering, updating of credits information by means of acknowledgments, packet size up to 4 Kbytes. However, there are several distinctive features of these protocols: using of a logical connection, different credits and credits counter measuring units.

After the analysis of the flow control mechanisms, we developed end-to-end flow control mechanism for the STP-ISS rev.2. This mechanism used only for the established transport connections, where the transmitter counts the free buffer space of the receiver by means of credits exchange. Each credit represents a byte of data transmitted in the packet. Since the number of stored packets and their size could be small, it is better not to use the “sliding window” flow control.

To ensure that transmitter always has the relevant information on credits STP-ISS has credits synchronization mechanism. This mechanism helps to avoid loss of credits information, which could be result of the acknowledgment packet corruption. Synchronization credits exchange between the receiver and a transmitter should be performed after each 10 data packets transmission. However, the parameter of 10 packets depends on number of generated packets, network bandwidth, bit error rate and data packets length. It requires additional analysis and modeling, which could help to correct this value.

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