

SpaceFibre Link Analysis

SpaceFibre 1, Long Paper

Stephen Mudie
STAR-Dundee Ltd
Dundee, Scotland
stephen.mudie@star-dundee.com

Steve Parkes
School of Computing
University of Dundee
Dundee, Scotland, UK
sparkes@computing.dundee.ac.uk

For those responsible for the design and implementation of a SpaceFibre network it is essential to be able to capture and view the traffic on a SpaceFibre link in order to help validate the link is operating as expected and debug the link should any unexpected behaviour be observed. STAR-Dundee Ltd have developed hardware independent SpaceFibre Link Analyser software for this purpose. This paper describes how the software views, combined with the traffic capture capabilities of the STAR Fire unit, can be used to perform SpaceFibre link analysis.

Index Terms— SpaceFibre, Link Analysis, STAR Fire

I. INTRODUCTION

SpaceFibre [1][2] is a multi-Gbits/s, on-board network technology for spaceflight applications that will soon become a formal European Cooperation for Space Standardization (ECSS) standard. At present the SpaceFibre enabled STAR Fire unit [3] from STAR-Dundee Ltd has allowed users to transmit and receive simple data patterns and perform some basic SpaceFibre link analysis for prototyping purposes. Over the past couple of years work has been undertaken to replace the software provided with the STAR Fire to leverage new advanced data generators and checkers and to greatly improve on the SpaceFibre link analysis capabilities. One result of this work has been the development of the hardware independent SpaceFibre Link Analyser software. This paper aims to describe how using this software, those responsible for the design and implementation of a SpaceFibre network might perform SpaceFibre link analysis. This is very important in order to help validate a SpaceFibre link operates as expected and to debug any unexpected behaviour.

In this paper the key requirements of the software are described along with the hardware currently supported, and a short overview of how the software is controlled is provided along with a description of the triggering capabilities. Each of the different SpaceFibre traffic views are briefly described and the key features of these summarised. Screenshots of different SpaceFibre traffic scenarios captured and displayed using the SpaceFibre Link Analyser software are then presented as simple examples of its use.

II. AIMS

Initial discussions regarding the SpaceFibre Link Analyser software highlighted a number of requirements outlined below.

- SpaceFibre traffic shall be captured when an event of interest occurs, for example a specific word such as a receive error or symbol such as EDF (End of Data Frame). This ensures the user captures the traffic they are most interested in.
- Three initial views shall be developed that display SpaceFibre traffic at the SpaceFibre symbol/word, frame and packet levels. This allows the user to thoroughly inspect the SpaceFibre traffic with varying levels of detail.
- The software shall be designed to support multiple device types capable of capturing/recording SpaceFibre traffic. This ensures continuity for users familiar with one device type switching to another. This also minimises custom development work for future devices with common functionality.

III. HARDWARE

The SpaceFibre Link Analyser software has been designed to support multiple device types with capture/recording capabilities. However, currently the STAR Fire is the only device type supported. The STAR Fire can transparently capture SpaceFibre traffic on a single link in both directions. Traffic capture can be triggered on detection of a SpaceFibre word, sequence of four symbols or an error. In addition to its capture capabilities, the STAR Fire can transmit and receive SpaceFibre traffic using data generators and checkers (these have recently been updated and now support more advanced data patterns), can route SpaceWire traffic over the SpaceFibre interfaces and can also decode SpaceFibre signals for use with a logic analyser.



Fig. 1. STAR Fire Unit

The STAR Fire has two SpaceFibre interfaces, two SpaceWire interfaces and two external triggers on the front of the unit. On the rear there are a further two external triggers, a USB 2.0 interface (soon to be USB 3.0), two MICTOR connectors and a power connector.

The STAR Fire is a great target for the SpaceFibre Link Analyser software as it provides the trigger and capture capabilities required, and can also act as a node for testing purposes, transmitting and receiving SpaceFibre traffic.

IV. OPERATION

Using the SpaceFibre Link Analyser software is quite simple. First the user should set the capture properties, for example the post trigger memory size. Next the capture trigger is configured, for example trigger on an SDF (Start of Data Frame) word. Then start SpaceFibre traffic capture (this causes the device to continuously capture to a circular buffer) and wait for the trigger to occur. When the trigger is detected or is forced by the user, the device memory is filled. The captured SpaceFibre traffic is then displayed in the different views.

V. TRIGGERING

Triggering is used to ensure SpaceFibre traffic of interest is captured. Before a trigger occurs SpaceFibre traffic is captured to a circular buffer continuously. When the trigger occurs, and the post trigger memory is filled, the contents of the capture buffer are accessed by the software and displayed.

The SpaceFibre Link Analyser software can trigger on nothing, a sequence of four SpaceFibre symbols or a SpaceFibre word. When trigger on nothing is selected, the trigger immediately occurs when the user chooses to stop capture. When trigger on word is selected, the user selects the word type and can optionally specify properties specific to that word. This is shown below for the SDF word. In this example the trigger will occur when an SDF word is detected on virtual channel one.

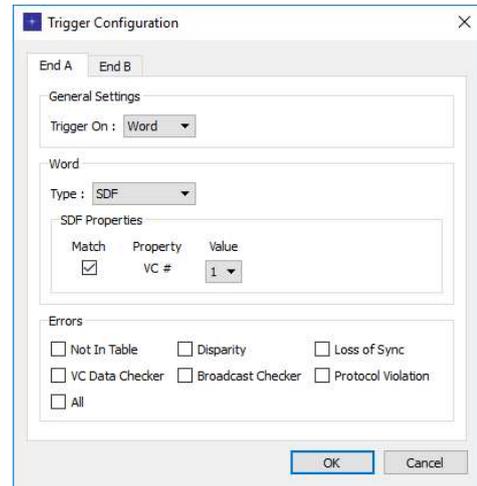


Fig. 2. Trigger on SpaceFibre Word

When trigger on symbol is selected, the user can select four consecutive symbols on which to trigger. This is shown in the screenshot below. In this example the trigger will occur when an SBF (Start of Broadcast Frame) word is detected on broadcast channel zero with sequence number five.

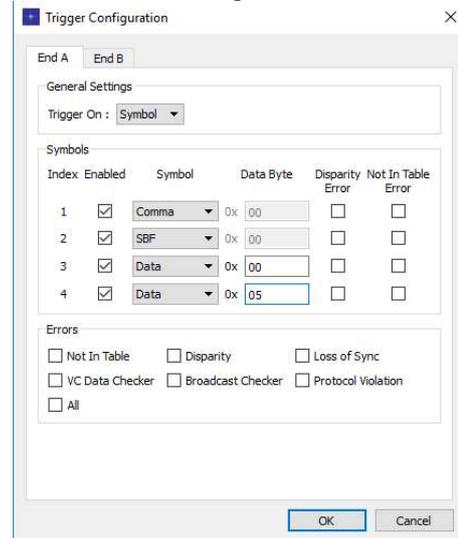


Fig. 3. Trigger on SpaceFibre Symbol

As is shown in the figures above, in addition to triggering on specific SpaceFibre symbols and words, the user can also choose to trigger on specific errors.

The triggering capabilities of the SpaceFibre Link Analyser software currently match the functionality provided by the STAR Fire. This could be extended further in the future with the addition of further advanced hardware triggering capabilities.

VI. SYMBOL VIEW

SpaceFibre uses 8B10B encoding to transfer 10-bit symbols over a SpaceFibre link. A symbol can be either a control or data symbol. A group of four consecutive symbols form a data word or control word.

The symbol view displays the captured SpaceFibre symbols and corresponding words travelling in both directions over a SpaceFibre link. One half of the symbol view displays the SpaceFibre traffic travelling in one direction whilst the other half displays the opposite direction. The left most column displays the time at which each word was captured relative to the trigger. For the STAR Fire unit this is simply the word index currently (the timing can be calculated knowing the link speed). For both SpaceFibre link directions there are four columns displaying four captured SpaceFibre symbols, plus a fifth column showing the SpaceFibre word the symbols equate to. Below is a screenshot of the symbol view showing data captured travelling in both directions.

	Symbol 1	Symbol 2	Symbol 3	Symbol 4	End A Word	End B Word	Symbol 1	Symbol 2	Symbol 3	Symbol 4
28	Comma	SDF	0x00	0x00	SDF (VC 0)	DATA (7792349)	0x72	0x2e	0x72	0x2e
29	0x5f	0x2e	0x5f	0x2e	DATA (7798975)	DATA (7793004)	0x73	0x2e	0x73	0x2e
30	0x60	0x2e	0x60	0x2e	DATA (7799552)	DATA (7799960)	0x74	0x2e	0x74	0x2e
31	0x61	0x2e	0x61	0x2e	DATA (7791038)	DATA (7794315)	0x75	0x2e	0x75	0x2e
32	Fill	Fill	Fill	Fill	DATA (EOP)	DATA (7799702)	0x76	0x2e	0x76	0x2e
33	0x62	0x2e	0x62	0x2e	DATA (7791862)	DATA (7799265)	0x77	0x2e	0x77	0x2e
34	0x63	0x2e	0x63	0x2e	DATA (7792130)	DATA (7799218)	0x78	0x2e	0x78	0x2e
35	0x64	0x2e	0x64	0x2e	DATA (7783174)	DATA (7799256)	0x79	0x2e	0x79	0x2e
36	0x65	0x2e	0x65	0x2e	DATA (7783828)	DATA (7799290)	0x7a	0x2e	0x7a	0x2e
37	0x66	0x2e	0x66	0x2e	DATA (7784484)	DATA (7799347)	0x7b	0x2e	0x7b	0x2e
38	Comma	ACK	0x51	0x00	ACK (Seq = 81)	DATA (7799801)	0x7c	0x2e	0x7c	0x2e
39	0x67	0x2e	0x67	0x2e	DATA (7785146)	DATA (7799358)	0x7d	0x2e	0x7d	0x2e
40	0x68	0x2e	0x68	0x2e	DATA (7782795)	DATA (7782013)	0x7e	0x2e	0x7e	0x2e
41	0x69	0x2e	0x69	0x2e	DATA (7786490)	DATA (7782886)	0x7f	0x2e	0x7f	0x2e
42	0x6a	0x2e	0x6a	0x2e	DATA (7797162)	DATA (7782244)	0x80	0x2e	0x80	0x2e
43	0x6b	0x2e	0x6b	0x2e	DATA (7787581)	DATA (7782176)	0x81	0x2e	0x81	0x2e
44	0x6c	0x2e	0x6c	0x2e	DATA (7788412)	DATA (7782835)	0x82	0x2e	0x82	0x2e
45	0x6d	0x2e	0x6d	0x2e	DATA (7789072)	DATA (EOP)	Fill	Fill	Fill	Fill

Fig. 4. Symbol View

The SpaceFibre symbol and word types supported are those found in the latest draft of the SpaceFibre standard (SpaceFibre ECSS Draft H6 [1]). These have long been defined.

VII. FRAME VIEW

SpaceFibre uses frames to manage the flow of information over a SpaceFibre link. There are three frame types: data, broadcast and idle frames. Data frames are transmitted across a SpaceFibre link over virtual channels whilst broadcasts are transmitted over a broadcast channel. Idle frames are transmitted when there are no data or broadcast frames to be transmitted. Virtual channels provide multiple independent communication channels over a single physical link.

The frame view was designed to display the data and broadcast frames in their appropriate channel, relative to the capture trigger time. As with the symbol view, the left most column displays the time relative to the capture trigger. Every other column represents a virtual channel or broadcast channel as indicated by the column header. Below is a screenshot of the frame view showing data frames captured travelling in both directions over four virtual channels on a SpaceFibre link.



Fig. 5. Frame View

Each data frame consists of a start of a data frame (SDF) control word, up to 64 data words and an end of data frame (EDF) control word. Each broadcast frame consists of a start of broadcast frame (SBF) control word, two data words and an end of broadcast frame (EBF) control word. The properties of the different control words are displayed in both the symbol and frame views, the EDF word sequence number in the screenshot above is an example of this.

VIII. PACKET VIEW

A SpaceFibre packet consists of a destination address, cargo and an end of packet (EOP) or error end of packet (EEP) marker. The SpaceFibre packet format is the same as SpaceWire, enabling simple connection between existing SpaceWire equipment and high-speed SpaceFibre links. This also means existing software designed to display SpaceWire packets can be used as a basis for a SpaceFibre packet display.

One such view is the SpaceWire packet view provided with the SpaceWire Link Analyser Mk2 software application. The SpaceWire Link Analyser Mk2 packet view has benefitted from the feedback of numerous users over several years, and many users of SpaceWire, and potentially users of SpaceFibre, are familiar with this display. For these reasons it was decided that the SpaceWire Link Analyser Mk2 packet view should form the baseline design for the SpaceFibre Link Analyser software packet view. Revisiting the design provided an opportunity to extend the reusability of the view (to support packet data formats of multiple device types rather than simply one device) and review the functionality offered.

The SpaceFibre packet view displays the captured SpaceFibre packets travelling in both directions over a SpaceFibre link. The left most column displays the time relative to the capture trigger. Every other column represents a virtual channel. This display allows the user to view the SpaceFibre traffic at the packet level without concerning themselves with the symbols, words and frames used to construct the packets. Work on this view is currently ongoing and should be complete in the near future.

IX. STATISTICS

In addition to the SpaceFibre Link Analyser software, the STAR Fire will also be supplied with a standalone STAR Fire Statistics application. This displays virtual channel and broadcast channel statistics associated with the STAR Fire SpaceFibre data/broadcast generators and checkers. A running count of data errors, EEPs and broadcast errors is displayed alongside the data generator rate and bandwidth reservation for each channel. Virtual channel lane utilisation is also graphed over time. Below is a screenshot of the STAR Fire statistics application.

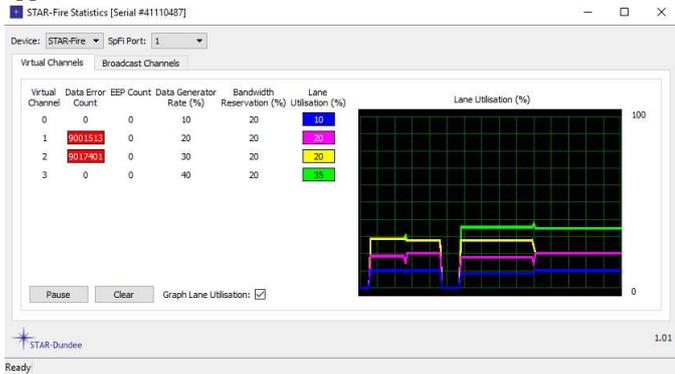


Fig. 6. STAR Fire Statistics

This immediately alerts the user to any errors detected by the data and broadcast checkers. The lane utilisation graph can be used to visualise the effect that changing the quality of service properties and data generator rate for each virtual channel has on lane utilisation.

X. FEATURES

The symbol, frame and packet views provide a great way of inspecting captured SpaceFibre traffic at different levels of detail. Each view is docked within a separate floating window. The positioning of these windows is user configurable. They can be placed side by side, above and below, or on top of each other in separate tabs. This allows the user to layout the views in the most effective manner for them.

Selection of SpaceFibre traffic in one view automatically selects and navigates to the corresponding traffic in the other views. This allows the user to navigate multiple views simultaneously and therefore makes them much easier to manage.

Each view shall have search capabilities specific to that view. This will allow the user to quickly locate SpaceFibre traffic of interest within very large quantities of data that could otherwise be difficult and time consuming to identify. Filtering options shall allow users to limit the traffic presented to only that pertinent.

XI. TESTING

Testing the SpaceFibre Link Analyser software was necessary throughout the development to ensure it behaved as expected. To test the SpaceFibre Link Analyser two SpaceFibre nodes were simulated transmitting and receiving SpaceFibre traffic to and from each other over a point to point

link. This was achieved using a STAR Fire ("STAR Fire N"). A second STAR Fire unit ("STAR Fire LA") was inserted on the link and configured to operate as a SpaceFibre Link Analyser. The diagram below shows the setup.

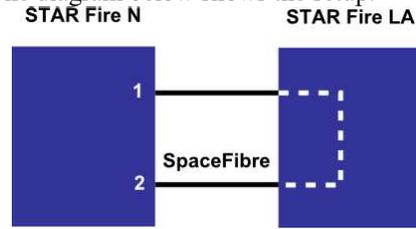


Fig. 7. SpaceFibre Link Analyser Test Setup

To configure STAR Fire N to transmit and receive SpaceFibre traffic the STAR Fire Controller application was used. The SpaceFibre port settings, quality of service, and advanced data generators and checkers can all be configured using the STAR Fire Controller. Numerous different configurations were used. Each could be saved and reused at a later date for regression testing. The STAR Fire Controller screenshot below shows virtual channel one settings for SpaceFibre port one of a STAR Fire unit.

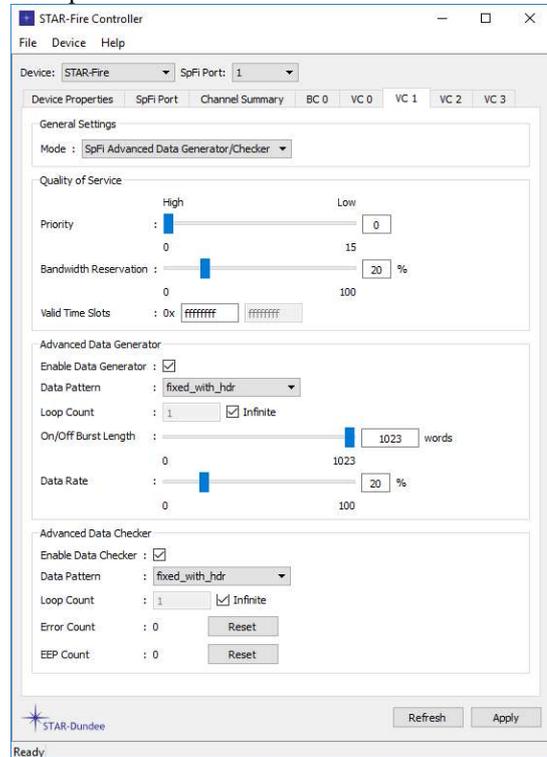


Fig. 8. STAR Fire Controller

The STAR Fire Controller application leverages the advanced data generators and checkers that have been added to the STAR Fire. These allow the user to specify data patterns of different types (fixed, increment, rotate right and rotate left), with an initial value, pattern length, packet length and four configurable header bytes. Below is a screenshot of the STAR Fire Controller dialog used to create and edit data patterns.

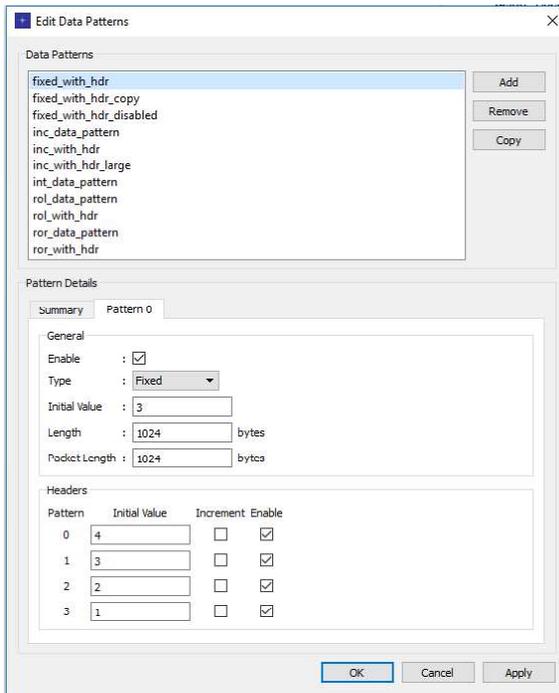


Fig. 9. STAR Fire Controller Advanced Data Patterns

XII. SPACEFIBRE TRAFFIC SCENARIOS

The test setup described was used to capture and analyse a range of typical scenarios encountered on a SpaceFibre link. Below are some typical SpaceFibre scenarios captured by the STAR Fire and displayed using the SpaceFibre Link Analyser software.

A. Lane Initialisation

Lane initialisation is responsible for initialising a lane prior to transfer of data frames, idle frames or broadcast frames. This is handled by a lane state machine. A handshake protocol is used to ensure that both ends of the lane have achieved synchronisation. Below is a screenshot of the symbol view showing part of the lane initialisation handshake where the near end is moving to the connected state.

Symbol 1	Symbol 2	Symbol 3	Symbol 4	Word	Word	Symbol 1	Symbol 2	Symbol 3	Symbol 4	
10158	Init Comma	LLCW	INIT1	INIT1	INIT1	INIT2	Init Comma	LLCW	INIT2	INIT2
10159	Init Comma	LLCW	INIT1	INIT1	INIT1	INIT2	Init Comma	LLCW	INIT2	INIT2
10160	Init Comma	LLCW	INIT1	INIT1	INIT1	INIT2	Init Comma	LLCW	INIT2	INIT2
10161	Init Comma	LLCW	INIT1	INIT1	INIT1	INIT2	Init Comma	LLCW	INIT2	INIT2
10162	Init Comma	LLCW	INIT1	INIT1	INIT1	INIT2	Init Comma	LLCW	INIT2	INIT2
10163	Init Comma	LLCW	INIT1	INIT1	INIT1	INIT2	Init Comma	LLCW	INIT2	INIT2
10164	Init Comma	LLCW	INIT2	INIT2	INIT2	INIT2	Init Comma	LLCW	INIT2	INIT2
10165	Init Comma	LLCW	INIT2	INIT2	INIT2	INIT2	Init Comma	LLCW	INIT2	INIT2
10166	Init Comma	LLCW	INIT2	INIT2	INIT2	INIT2	Init Comma	LLCW	INIT2	INIT2
10167	Init Comma	LLCW	INIT2	INIT2	INIT2	INIT2	Init Comma	LLCW	INIT2	INIT2
10168	Init Comma	LLCW	INIT3	INIT3	INIT3	INIT2	Init Comma	LLCW	INIT2	INIT2
10169	Init Comma	LLCW	INIT3	INIT3	INIT3	INIT2	Init Comma	LLCW	INIT2	INIT2
10170	Init Comma	LLCW	INIT3	INIT3	INIT3	INIT2	Init Comma	LLCW	INIT2	INIT2
10171	Init Comma	LLCW	INIT3	INIT3	INIT3	INIT2	Init Comma	LLCW	INIT2	INIT2
10172	Init Comma	LLCW	INIT3	INIT3	INIT3	INIT2	Init Comma	LLCW	INIT2	INIT2
10173	Init Comma	LLCW	INIT3	INIT3	INIT3	INIT2	Init Comma	LLCW	INIT2	INIT2
10174	Init Comma	LLCW	INIT3	INIT3	INIT3	INIT2	Init Comma	LLCW	INIT2	INIT2
10175	Init Comma	LLCW	INIT3	INIT3	INIT3	INIT2	Init Comma	LLCW	INIT2	INIT2
10176	Init Comma	LLCW	INIT3	INIT3	INIT3	INIT2	Init Comma	LLCW	INIT2	INIT2
10177	Init Comma	LLCW	INIT3	INIT3	INIT3	INIT2	Init Comma	LLCW	INIT2	INIT2
10178	Init Comma	LLCW	INIT3	INIT3	INIT3	INIT2	Init Comma	LLCW	INIT2	INIT2

Fig. 10. Lane Initialisation Handshake

B. Frame Acknowledgment

Each correctly received SpaceFibre frame or FCT (Flow Control Token) is acknowledged with an ACK (acknowledgement) control word. Below are two combined screenshots of the symbol view showing a data frame with sequence number +47 captured travelling in one direction and the corresponding +47 ACK travelling in the opposite direction.



Fig. 11. Data Frame Acknowledgement

C. Error Recovery

A negative acknowledgement (NACK) is used to indicate that a data frame, broadcast frame or FCT has not been received correctly. NACKs are used to support link error recovery. In the symbol view screenshot below a NACK is captured indicating that a data frame, broadcast frame or FCT has not been received correctly.



Fig. 12. Symbol View: Negative Acknowledgement

When the NACK is received this initiates the error recovery operation. The frame view screenshot below shows the retransmission of data frame 89. Data frame 89 was retransmitted as the NACK indicated that 88 was the sequence number of the last successfully received data frame, broadcast frame or FCT.

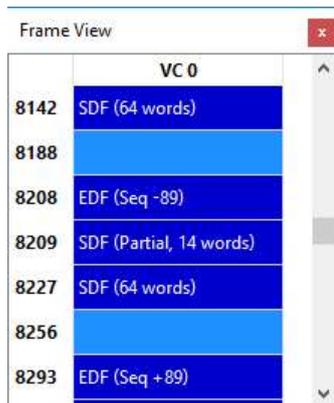


Fig. 13. Frame View: Data Frame Retransmission

D. Frame Precedence

SpaceFibre includes low latency event signalling and time distribution with broadcast messages. Broadcast frames have higher precedence than data frames ensuring broadcasts have minimum latency. Data frames have greater precedence than idle frames. Below is a screenshot of the symbol and frame views showing a broadcast frame embedded within a data frame.



Fig. 14. Broadcast Frame Embedded in a Data Frame

The data frame was part way through being transmitted when the broadcast frame became ready to send. The transmission of the data frame was suspended and the broadcast frame was sent immediately. After the broadcast frame was transmitted, the remainder of the data frame was transmitted.

E. Quality of Service Example

Each virtual channel is assigned quality of service (QoS) parameters that are used to determine which channel should be permitted to transmit data at any one time. Priority, bandwidth reservation and scheduling are used to do this. Below is a screenshot of the frame view showing four virtual channels where VC 0 is assigned 60% of the bandwidth, VC 1 10%, VC

2 10% and VC 3 10%. As you can see VC 0 is utilising the link far more than the other virtual channels as a result.



Fig. 15. Frame View QoS Example

XIII. CONCLUSION

As the popularity of SpaceFibre increases so too will the demand to perform effective SpaceFibre link analysis. This paper has described the current capabilities of the SpaceFibre Link Analyser software in an effort to make those responsible for the design and implementation of SpaceFibre networks aware of the existing tools available to them.

Currently in conjunction with the STAR Fire unit, users can capture SpaceFibre traffic in response to a trigger event. Once captured this traffic is automatically translated and displayed in symbol, frame and packet views. These views are all selection synchronised for easy navigation of the data. In the future additional functionality will be added to the existing views and additional devices will be supported by the SpaceFibre Link Analyser software.

REFERENCES

- [1] S. Parkes, A. Ferrer, A. Gonzalez, C. McClements and M. Suess, ECSS SpaceFibre Standard Draft H6
- [2] S. Parkes, <https://www.star-dundee.com/spacefibre-users-guide>, SpaceFibre User's Guide, STAR-Dundee Website
- [3] STAR-Dundee, https://www.star-dundee.com/sites/default/files/STAR%20Fire_0.pdf, STAR Fire Data Sheet, STAR-Dundee Website