STAR-ULTRA SINGLE-LANE ROUTER: AN ELEVEN-PORT ROUTING SWITCH FOR TEST AND DEVELOPMENT OF SPACEFIBRE SYSTEMS

Dave Gibson[1], Andrew MacLennan[1], Chris McClements[1], Stuart Mills[1], Stephen Mudie[1], Steve Parkes[1], Alan Spark[1], Marti Farras Casas[2], Albert Ferrer Florit[2], and Alberto Gonzalez Villafranca[2]

Presenter: Dave Gibson

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[1] *STAR-Dundee Ltd, Dundee, Scotland, UK.*

[2] *STAR-Barcelona SL, Sant Cugat del Valles, Barcelona, Spain.*

Email: david.gibson@star-dundee.com

ABSTRACT

A SpaceFibre [1] network acts like multiple SpaceWire [2] networks running in parallel on top of the same physical network. These parallel networks are referred to as SpaceFibre Virtual Networks (VNs). Each VN consists of a set of SpaceFibre Virtual Channels (VCs), one for each SpaceFibre link used by the VN. VCs within a VN each have their own configurable Quality-of-Service (QoS) parameters, allowing a VN to have allocated bandwidth, priority, and a schedule.

The STAR-Ultra Single-Lane Router is a SpaceFibre single-lane routing switch with eight single-lane SpaceFibre ports, an internal Remote Memory Access Protocol (RMAP) [3] configuration port, and two internal Advanced eXtensible Interface (AXI) ports connected to an eight-lane Gen 3 Peripheral Component Interconnect Express (PCIe) interface. It can be used as a standalone routing switch or as a SpaceFibre interface board with an embedded routing switch. Each single-lane SpaceFibre port can operate at a lane signalling rate of up to 6.25 Gbit/s, providing a unidirectional data rate of approximately 4.8 Gbit/s or bidirectional data rate of approximately 4.6 Gbit/s on each port. In addition to its routing capabilities, the AXI ports connected to the PCIe interface allow high-performance data transfer to and from software running on a host computer.

This paper presents the architecture of the STAR-Ultra Single-Lane Router, provides details of its hardware capabilities and software support, and provides performance results when transmitting and receiving packets from software running on a host computer.

1 INTRODUCTION

The STAR-Ultra Single-Lane Router is a PCIe board with eight single-lane SpaceFibre ports available via two Quad Small Form-Factor Pluggable Plus (QSFP+) ports on its front-panel. The two internal AXI ports on the routing switch are connected to a Gen 3 x8 PCIe interface available via an x16 PCIe connector.

A photograph of the STAR-Ultra Single-Lane Router's front-panel is provided in Figure 1.

Figure 1: STAR-Ultra Single-Lane Router Front Panel

As shown in Figure 1, the STAR-Ultra Single-Lane Router has two QSFP+ connectors. SpaceFibre ports 1 to 4 are available via the first QSFP+ connector, and SpaceFibre ports 5 to 8 are available via the second.

The individual SpaceFibre ports can be separated out using a QSFP+ to four SFP+ cable assembly. The SFP+ cable assemblies can then be connected to SpaceFibre devices with SFP+ connectors or converted into other formats using a variety of adaptors such as SFP+ to SMP or SFP+ to SpaceFibre Type-C. Additionally, the QSFP+ connectors can be used with fibre optic modules.

2 ROUTER ARCHITECTURE

The internal architecture of the STAR-Ultra Single-Lane Router is illustrated in Figure 2.
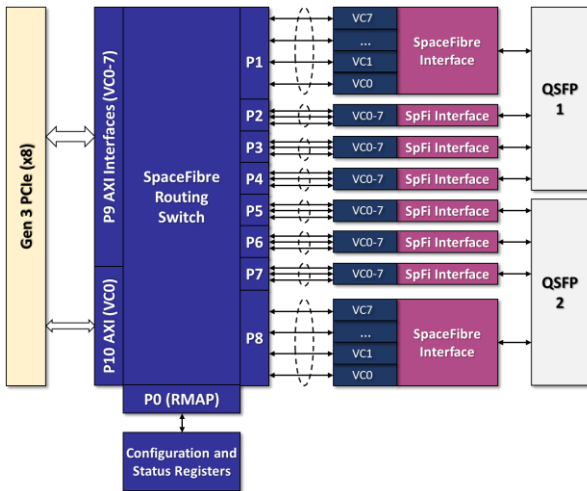
Figure 2: STAR-Ultra Single-Lane Router Internal Architecture

As shown in Figure 2, at the centre of the STAR-Ultra Single-Lane Router architecture is the SpaceFibre routing switch, connecting the SpaceFibre ports (P1-P8), AXI ports (P9 and P10), and the configuration port (P0).

2.1 SpaceFibre Ports

There are eight single-lane SpaceFibre interfaces [4] attached to the SpaceFibre routing switch on P1-P8. The first four ports (P1-P4) are connected to QSFP 1, and the second four ports (P5-P8) are connected to QSFP 2.

The SpaceFibre interfaces each have eight VCs with independently configurable QoS parameters. The lane signalling rate for each SpaceFibre port is configurable up to a maximum rate of 6.25 Gbit/s.

2.2 AXI Ports

There are two AXI interfaces attached to the SpaceFibre routing switch on P9 and P10, allowing software access to the SpaceFibre network over the PCIe interface.

The AXI interface on P9 is used for general-purpose packet transmitting and receiving on eight VCs. Each VC has a dedicated software channel that can be opened unidirectionally or bidirectionally in user applications.

The AXI interface on P10 is used for local configuration of the device using VC 0. It has a dedicated software channel used by the STAR-System [5] software suite for device configuration. This removes a conflict on VC 0 as user applications can transmit and receive on P9 VC 0, while local device configuration is performed by STAR-System on P10 VC 0.

In addition to the two AXI ports used to send and receive packets, there is an interface for sending and receiving SpaceFibre Broadcast Messages (BMs) with its own dedicated software channel that can be opened unidirectionally or bidirectionally in user applications.

2.3 Configuration Port

The configuration port provides RMAP access to the SpaceFibre routing switch's configuration and status registers. These registers allow for configuration and monitoring of the routing table, network management parameters, VCs, ports, links, and lanes.

Configuration and monitoring of the routing switch is simplified by the provided STAR-System SpaceFibre Configuration Application Programming Interface (API) and associated graphical applications.

3 SOFTWARE

The STAR-Ultra Single-Lane Router has extensive software support, consisting of three main layers:

- STAR-Ultra PCIe Driver
- STAR-System APIs
- Graphical Applications

The STAR-Ultra PCIe driver is a high-performance PCIe kernel-space driver for Windows and Linux operating systems.

The STAR-System APIs, available in C, C++, and Python, are built on top of the STAR-Ultra PCIe driver and are used for sending and receiving packets, sending and receiving broadcast messages, and device configuration.

The graphical applications are built on top of the STAR-System APIs and provide graphical interfaces for common functions such as sending and receiving packets, and device configuration and monitoring.

3.1 STAR-Ultra PCIe Driver

The STAR-Ultra PCIe driver was designed for high-performance SpaceFibre and SpaceWire interface and routing devices. It allows SpaceFibre traffic to be transmitted and received using software running on a host PC at data rates of over 10 Gbit/s in each direction.

The STAR-Ultra PCIe driver supports multiple devices including the STAR-Ultra PCIe [6], SpaceWire PCIe Mk2 [7], and STAR-Ultra Single-Lane Router.

3.2 STAR-System APIs

STAR-System is the common software suite supporting all current STAR-Dundee SpaceFibre and SpaceWire interface and routing devices. STAR-System includes C, C++, and Python APIs for integrating devices into custom software applications.

For the STAR-Ultra Single-Lane Router, a new Generic SpaceFibre Configuration API was designed and

developed. The Generic SpaceFibre Configuration API provides a simple method for configuration and monitoring of the SpaceFibre routing table, network management parameters, VCs, ports, links, and lanes.

3.3 Graphical Applications

STAR-System includes a range of graphical applications used to perform common functions such as sending and receiving packets; configuring and checking packet formats; executing RMAP transactions; and performing in-field device updates.

For the STAR-Ultra Single-Lane Router, a new generic device configuration and monitoring application was designed and developed, based on the Hi-SIDE Monitoring and Control System [8].

The generic device configuration and monitoring application, called STAR Device Control, provides a graphical interface for accessing RMAP target memory regions, register groups, registers, and fields.

Any device with one or more RMAP target register interfaces can be described in a spreadsheet format, loaded into the software, and accessed using a STAR-System device acting as the RMAP initiator.

Additionally, the STAR Device Control software supports configuration of SpaceFibre and SpaceWire devices over an Ethernet network and between different operating systems and languages. For example, the host of the device acting as an RMAP initiator can be set up as a device server on a Windows host, and a client can configure SpaceFibre or SpaceWire devices remotely from a Linux host.

A screenshot of the STAR Device Server application, with a STAR-Ultra Single-Lane Router used as the RMAP initiator device for configuring three other STAR-Ultra Single-Lane Routers, is shown in Figure 3.
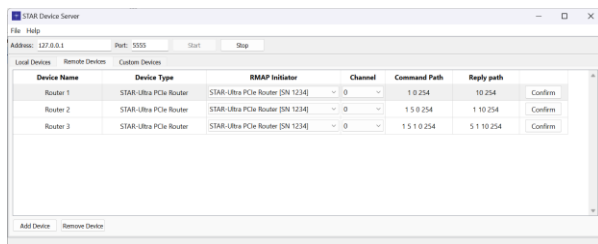

Figure 3: STAR Device Server Application

As shown in Figure 3, a device server has been set up with three remote STAR-Ultra Single-Lane Router devices. For each remote device, the RMAP initiator and channel is selected, and the command and reply paths are configured.

After setting up the device server, a client can configure and monitor remote devices either locally or across an

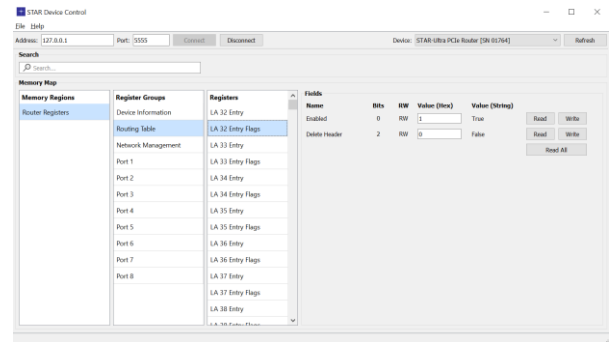Ethernet network, using the client interface as shown in Figure 4.

Figure 4: STAR Device Control Application

As shown in Figure 4, remote devices can be selected in the application and their memory regions, register groups, registers, and fields are made available for reading and writing.

4 TEST SYSTEM

The architecture of the STAR-Ultra Single-Lane Router test system is illustrated in Figure 5.
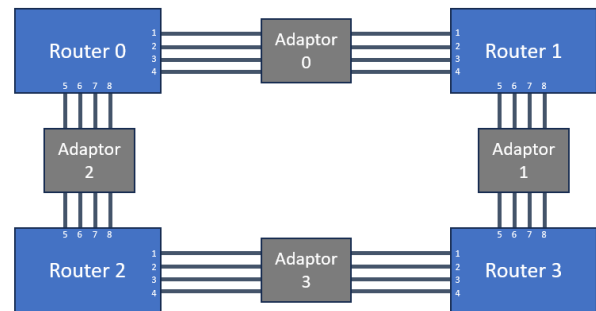

Figure 5: STAR-Ultra Single-Lane Router Test System Architecture

As shown in Figure 5, there are four STAR-Ultra Single-Lane Routers with all SpaceFibre ports connected in a ring topology using four adaptor boards.

The QSFP+ connectors on each STAR-Ultra Single-Lane Router are first separated using QSFP+ to SFP+ cable assemblies then connected to SFP+ to SFP+ adaptor boards. The adaptor boards allow any SpaceFibre port to be connected to any other SpaceFibre port in the network.

A photograph of the STAR-Ultra Single-Lane Router test system is shown in Figure 6.
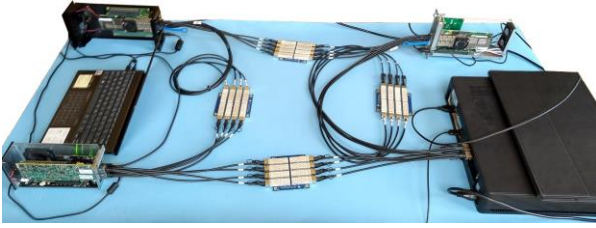
Figure 6: STAR-Ultra Single-Lane Router Test System

As shown in Figure 6, one of the STAR-Ultra Single-Lane Router boards is connected directly to a host PC, in the bottom right of the photograph. The other three boards are connected to laptops via three different PCIe to Thunderbolt 3 adaptors.

5 PERFORMANCE RESULTS

STAR-System includes a performance testing tool for measuring the transmit and receive performance of SpaceWire and SpaceFibre devices.

The following performance tests use the STAR-System Performance Tester application to transmit packets of increasing sizes continuously while measuring data rate and CPU utilisation. The receiver for these tests was implemented using the STAR-System "ex" receive mode, which uses pre-allocated user buffers to minimise the receive overhead which can improve performance for small packets.

The host computer for the performance tests was running Windows 11 Pro with the following specifications:

- ASUS PRIME H310i PLUS R2.0 Motherboard
- Intel Core i5 Six Core Processor i5-9600 (3.1GHz) 9MB Cache
- 16 GB Corsair VENGEANCE DDR4 2400MHz
- 240 GB ADATA SU630 SSD

The first performance test used a single VC on one AXI port, sending packets of increasing size routed over one SpaceFibre port and back to the VC on the AXI port.

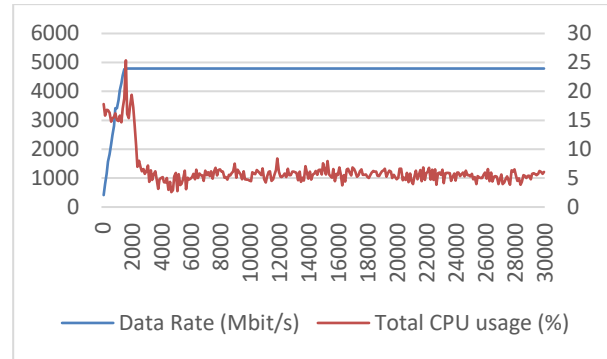The results of the first test are shown in Figure 7.

Figure 7: One VC, One Port, 10-30K Packets

In Figure 7, the chart shows the data rate (Mbit/s) on the left vertical axis; the total CPU usage (%) on the right vertical axis; and the packet size (bytes) on the horizontal axis.

As shown in Figure 7, the data rate reaches the maximum unidirectional data rate of approximately 4.8 Gbit/s for one single-lane SpaceFibre port running at a lane signalling rate of 6.25 Gbit/s.

The second performance test used two VCs on two AXI ports, sending packets of increasing size routed over separate SpaceFibre ports and back to the two VCs on the AXI ports.

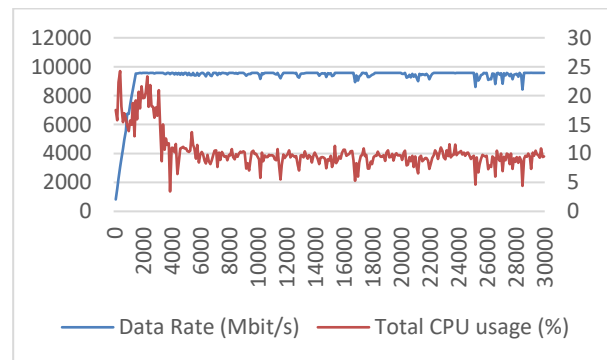The results of the second test are shown in Figure 8.

Figure 8: Two VCs, Two Ports, 10-30K Packets

As shown in Figure 8, the data rate reaches the maximum unidirectional data rate of approximately 9.6 Gbit/s for two single-lane SpaceFibre ports each running at a lane signalling rate of 6.25 Gbit/s.

6 CONCLUSIONS

The STAR-Ultra Single-Lane Router is an eleven-port SpaceFibre routing switch with eight single-lane SpaceFibre interfaces, two AXI ports for interfacing with the host, and an RMAP configuration port. It has an x8 Gen 3 PCIe interface for interfacing with the host, available via an x16 PCIe connector.

The SpaceFibre interfaces are available using the board's QSFP+ connectors, which provide a simple and flexible method for connecting to other SpaceFibre devices directly or using available adaptors and cable assemblies to convert to other connector types.

The STAR-Ultra Single-Lane Router has a high-performance PCIe driver for interfacing with the host and it has extensive software support using the STAR-System APIs and graphical applications, including a new generic device configuration application.

7   REFERENCES

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