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Experimental Demonstration of 5G Fronthaul and Backhaul Convergence based on FPGA-based Active Optical Transport

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Abstract *We demonstrate a dynamic frame-based optical network in support of a 5G transport supporting both Backhaul and Fronthaul functionalities exploiting FPGA-based real-time optical active technologies. This solution is successfully evaluated over a city field trial with <1dB power penalty.*

Introduction

5G networks require innovative network technologies to support the key 5G performance indicators (KPIs)[1] such as high bandwidth and sub-millisecond end-to-end latency. The 5G-XHaul[2] project, which is part of the 5G Infrastructure Public Private Partnership (5G-PPP), leverages an optical transport solution to support 5G networking and address its high bandwidth connectivity and low latency requirements. 5G-Xhaul proposes a hybrid passive and active optical network that is integrated with wireless networks technologies to shape a flexible transport infrastructure. 5G-Xhaul also suggests a new Centralised Radio Access Network (C-RAN) architecture supporting both Backhaul (BH) and Fronthaul (FH) functionalities to provision the required 5G capacity and flexibility.

The Time-Shared Optical Network (TSON) [3] has been proposed as a dynamic optical network solution to offer high bandwidth and low-latency connectivity in support of the 5G technology requirements and provision jointly optical BH and FH services. TSON is an active Wavelength Division Multiplexing (WDM) solution which provides variable sub-wavelength switching granularity and the ability to dynamically allocate optical bandwidth elastically[3]. The TSON baseline technology has been extended over the course of the 5G-XHaul project to support multi Ethernet clients for BH, and Common Public Radio Interface (CPRI) integration for FH services.

This paper introduces the TSON 5G-XHaul implementation to address the varying FH capabilities needed by the different Remote Radio Head (RRH) systems and the BH requirements and interfaces that the 5G-XHaul transport network needs to support. The extended TSON is the first multiple protocol programable interface that meets 5G KPIs. In addition, the operation of the extended 5G-XHaul TSON technology was demonstrated and evaluated over the Bristol City Metro Fibre Infrastructure. This demonstration involved the implementation of TSON active programmable nodes in the City Metro Infrastructure.

TSON technology overview

TSON is a multi-wavelength fully bi-directional synchronous and flexible system. Its network implementation consists of Field Programmable Gate Array (FPGA) optoelectronics platforms integrated with advanced optical components to enable high performance processing and transparent switching and transport. This solution includes two different types of nodes, the edge nodes and core nodes. TSON edge nodes provide the interfaces between wireless, passive optical network (PON), and data centre (DC) domains. The ingress TSON edge nodes are responsible for traffic aggregation and mapping, while the egress edge nodes have the reverse functionality. TSON core nodes do not carry out any data processing but need to switch the traffic optically based on the client's requirements. As TSON exploits the benefits of software defined networking, the parameters of the TSON nodes are programmable by the SDN controller. These parameters include, for example, quality of Transmission (QoT) overhead programmable, time-slice numbers in a frame programmable and time-slice allocation. When an operator or service provider requests to set up a network service, the TSON nodes select the corresponding parameters to fulfil the request by composing a dedicated network function slice on the node. Fig. 1 shows the TSON role in the 5G-XHaul project. To become suitable to support FH and BH services in 5G-XHaul, TSON is extended to support multi Ethernet clients for backhaul and CPRI integration for fronthaul services.

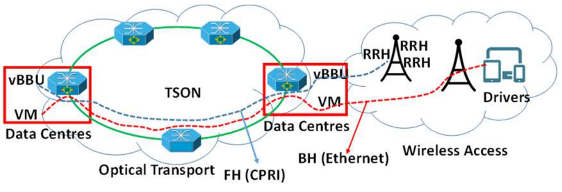

Fig. 1: TSON role in the 5G-XHaul project

BH services over TSON - supporting Ethernet

The extensions of the TSON clients are only limited to the number of available transceivers on the FPGA boards used. We have extended the TSON Ethernet client ports to two for the 5G-XHaul solution, to support BH services in accordance to the final demonstration architecture.

Fig. 2 shows the extended TSON solution to support BH service requirements in 5G-XHaul. The multi-line client TSON follows the legacy one client TSON where the clients are using different wavelengths. In addition, Ethernet clients can use a common wavelength if the total bandwidth of the clients is less than the available line rate (10 Gbps are used for the implemented FPGA evaluation board). In this scenario, the packets are delivered to the related Ethernet clients at the egress nodes based on their header information (VLAN tag for 5G-XHaul[4]). This scenario is very well aligned with the overall 5G-XHaul architecture that relies on the integration of TSON with Millimetre Wave (mmWave) wireless transport technologies[5] and more specifically the Blue Wireless Typhoon modules supporting up to 3.07Gbps throughput.

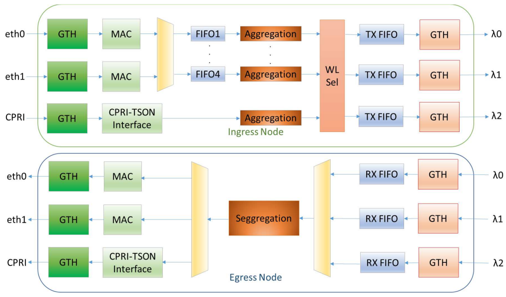

Fig. 2: TSON extension for backhaul services with multi Ethernet clients and CPRI integration high level

FH services over TSON -CPRI extension

TSON's extension performed to enable native CPRI can support up to option 5 of the CPRI line bit rate (i.e. 4.9152Gbps, 8B/10B line coding), in accordance to the 5G-XHaul Baseband Unit (BBU) and RRH implementation. However, higher line rate options are feasible applying the same generic methodology for the TSON-CPRI integration. TSON can support varying service requirements as its operational characteristics can be dynamically modified.

We have configured the Xilinx Transceiver Intellectual Property Core (IP core) for the CPRI protocol option 5. The reference clock frequency and data width for this IP core is 122.88 MHz and 32-bit respectively. The IP core configuration uses 8B/10B encoding/decoding. Therefore, 4-bit control signals are available to indicate if data are special characters or regular data for both the receiving and transmitting sides. Fig. 2 shows the TSON edge node and CPRI integration high level architecture. In this, the CPRI transceiver receives CPRI frames and passes them to the CPRI-TSON interface at the ingress side. The CPRI-TSON interface is responsible for the Clock Domain Crossing (CDC) from 122.88 MHz to 156.25 MHz, which involves clock design and mapping the 32-bit data and 4-bit control to 64-bit corresponding to the TSON data width. Once the CPRI frames reach the aggregation block then according to the Look Up Table (LUT) information of the time-slice allocation, the aggregation block calculates the frames needed to construct the burst, aggregates the frames, waits for the valid time-slice, and finally sends the burst into a different wavelength according to the (First-In-First-Out) queuing (FIFO) discipline. The egress site has the reverse functionality.

Testbed Setup and Implementation

We have employed a Xilinx VC709 evaluation board for the implementation. Fig. 3 shows the TSON architecture for 5G-XHaul. The configuration contains two TSON edge nodes. TSON edge node 1 and 2 are connected to three clients comprising two Ethernet and one CPRI ports. In the upstream scenario, TSON Edge node 1 aggregates two 4.4Gbps Ethernet into one 8.8Gbps flow and sends both CPRI and the aggregated Ethernet packets to TSON Edge node 2. The TSON Edge 2 node receives the packets from the Ethernet and CPRI ports. The Ethernet packets are segregated to two ports based on the VLAN and CPRI traffic maps the CPRI client. Each client is looped back on TSON node 2. The downstream scenario functionality is the same as the upstream. 4.4Gbps is an arbitrary value which is higher than the Blue Wireless Typhoon throughput for the stress test. In order to obtain accurate measurements, the aggregation of Ethernet and CPRI traffic is not considered in the scenarios selected.

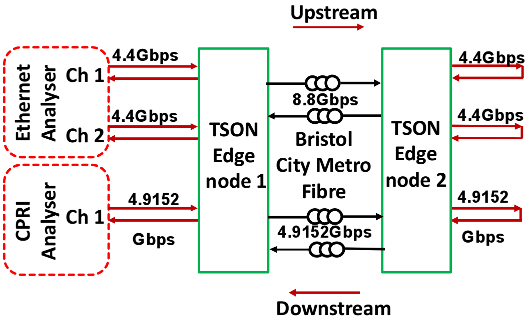

Fig. 3: TSON 5G-XHaul implementation architecture for 5G-XHaul final demonstration

Experimental Results

Three different scenarios are considered for experimental evaluation. The first scenario

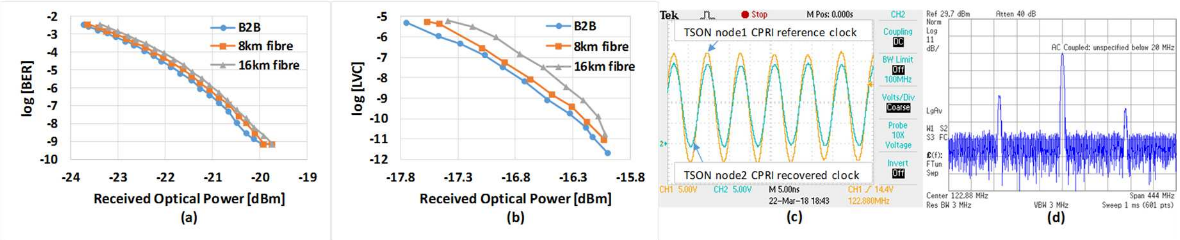

Fig. 4: (a)Ethernet BER measurements, (b)CPRI LVC measurements, (c)TSON node1 CPRI reference clock and TSON node2 CPRI recovered clock, and (d) CPRI recovered clock spectrum

includes both FPGAs connected back-to-back with short fibres. In the second and third scenarios, the proposed technologies are evaluated over the Bristol City Metro Fibre with 8km and 16 km, respectively, of standard single-mode fibre (SSMF). A traffic analyser (Anritsu MT1100) generates/receives two Ethernet traffics to/from the TSON edge node 1 at 4.4Gbps with fixed frames of 1500B length. The Ethernet performance parameters under consideration include Bit Error Rate (BER) and latency. Latency is defined as the time difference between the arrival of a frame at the analyser, and its departure from the analyser. Also, the traffic analyser generates/receives CPRI traffic to/from the TSON node 1 at 4.9152Gbps. The CPRI performance parameters considered include Line Code Violations (LCV) (8B/10B decoding) ratio and latency. Fig. 4.a shows the Ethernet BER measurements as a function of received optical power for the different considered scenarios. The BER curves show that the penalty observed for the case of 8km of SSMF transmission over the Bristol City Metro Fibre Infrastructure compared to the back-to-back (B2B) performance is negligible. A penalty lower than 1dB is observed for 16km transmission. Fig. 4.b demonstrates the CPRI LVC measurements as a function of received optical power for the different scenarios considered. The LVC curves reveal that the penalty for both 8km and 16km compared to the B2B case is as low as <1dB.

The VC709 includes a Silicon Labs Si5324 jitter attenuator on the board. The Si5324 is used for CPRI clock recovery from a user-supplied SFP/SFP+ module and use the jitter-attenuated recovered clock to drive the reference clock inputs of a GTH transceiver. Fig. 3c illustrates the TSON node 1 CPRI reference clock and TSON 2 recovered clock. As observed in Fig. 3c,the CPRI clock is succesfully recovered. Fig. 3d shows the CPRI recovered clock spectrum.

Tab. 1: Ethernet and CPRI round-trip latency

Destination	Ethernet Latency [us]	CPRI Latency[us]
B2B	3.141	0.89
8km	86.044	84.09
16km	169.075	166.75

Tab. 1 displays the round-trip latency for Ethernet and CPRI scenarios. In both cases the TSON edge node worst-case latency is less than 4%.

Conclusions

We have proposed and extended the TSON technology in order to provide a dynamic optical transport solution in support of the overall 5G-XHaul architecture to become suitable to support FH and BH services. To support BH services TSON has been modified to handle more Ethernet client ports able to be multiplexed and demultiplexed at the TSON edge nodes. This extension maintained all previous features of TSON and added increased functionality and flexibility by multiplexing two or more clients to one wavelength. Thus, making TSON able to efficiently support low bandwidth Ethernet clients. TSON was also appropriately extended to support FH services through CPRI integration. We have implemented and evaluated the 5G-XHaul final demonstration architecture for our 5G active nodes using the Bristol City Metro Fibre Infrastructure. Results showed that a negligible power penalty occurs when an optical fibre link of 8km length is used, with respect to the B2B configuration. For a 16km optical fibre link, the power penalty is as low as 1dB, denoting the reliability of the enhanced technology over dark fibres.

Acknowledgements

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