Experimental Evaluation of Server Centric Passive Optical Network Based Data Centre Architecture

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ABSTRACT
Passive optical networks (PON) technology has recently been proposed as a solution for scalability, energy efficiency, high capacity, low cost, flexibility and oversubscription issues in data centres. This paper experimentally demonstrates and discusses the implementation of a server centric PON based data centre architecture with high speed and reliability. The architecture is set up using a set of servers grouped into racks directly connected together and to the Optical Line Terminal (OLT) through gateway servers. The switching and routing functionalities have been embedded into servers using 4x10GE Xilinx NetFPGA. Flow continuity has been observed through live video streaming using IP cameras transmitting over up to 110 km optical connections through WDM nodes and the PON network.

Keywords: Passive optical Networks, NetFPGA, ONU, PON, NIC, WDM

1. INTRODUCTION
In recent years, higher data rates and power efficiency in data centres have become essential, hence several studies have been carried out in optimising energy efficiency and architectures in data centres and the core networks connecting them [1]-[10]. In order to validate the results of these studies, experimental work was needed to deploy and evaluate these architectures.

As shown in Figure 1 one of our previously designed PON based data centre network architectures [11] proposed a server centric architecture that provides high speed communication between servers. The architecture subdivides the data centre into PON cells, where each cell contains servers grouped in racks with an OLT providing control and interfaces. To facilitate the communication between servers in different groups within the same rack an optical backplane is used [12]. Each rack has a group of servers that handles the aggregation of traffic between the rack and the OLT. Other groups are directly connected to different groups within other racks to provide inter-rack communication. Data between the OLT and the racks is routed through a coupler (Time Division Multiplexing (TDM)) or via an arrayed Waveguide Grating (AWGR) that makes use of Wavelength Division Multiplexing (WDM) [11], [13] - [15].

Studies have been carried out to find a solution for the problem of higher data rate demands within data centres, as well as faster processing, energy efficiency and scalability. One of these studies introduced the NetFPGA board, a Field Programmable Gate Arrays (FPGA) based networking solution. FPGAs were developed to enhance switching, routing and processing of network data. The NetFPGA Platform is an open source hardware and software platform composed of a large programmable Xilinx FPGA, PCI interface, static RAMs (SRAMs), Double Data Rate (DDR2) SDRAM, quad-port physical-layer transceiver (PHY) for transmission and reception [16]. In this paper the NetFPGA-10G is used as a Network Interface Card (NIC) for the servers in the processing cells. It is an FPGA-based PCI Express board with four 10-Gigabit SFP+ interfaces, an x8 gen1 PCIe adapter card incorporating Xilinx’s Virtex-5 TX240T FPGA [16].

In this paper an experimental implementation of the proposed data centre architecture has been carried out to test its operation when two instances of the architecture are connected through different platforms over long distances of over 110 km of optical interconnections passing through a core network and a PON cell.

2. ARCHITECTURE IMPLEMENTATION
The implementation of the server centric passive optical network data centre architecture shown in Figure 1 was achieved by using three racks, each containing three servers connected via a 10 Gbps Cisco Switch. Racks are connected together using an optical link via a media converter. Figure 2 Shows the IP addressing and connectivity of the servers within the same rack and among different racks. Figure 3 shows the experimental deployment of the architecture in our laboratories. As a solution to the unavailability of the optical backplane an electronic switch was used to connect servers and the servers operating system handled the routing and relaying of traffic.
To implement the routing functionalities relay servers were equipped with MikroTik OS; a specialized Linux Kernel operating system, while the other servers operated using Ubuntu Operating system.

The server centric PON architecture is utilised as a processing cell. Each rack is given a different IP network and racks communicate through gateways among themselves. The variety of connections and alternative routes between servers provides high reliability. Figure 2 demonstrates the networks and IP assignment and it shows the gateway servers within each rack that are used for traffic relaying. Relay servers are configured with two IP addresses for intra-rack communication and inter-rack communication. All other servers in the network were set up with the gateway IP address for inter-rack communication, [19].

An IP over DWDM core network is used to demonstrate communication between multiple data centres located in multiple cities with over 100 km of optical fibre links as shown in Figure 4 [20]-[29]. Each core node is 100 Gbps MRV/ADVA DWDM node. Multiplexers/Demultiplexers are used on the C-band supporting 80 wavelengths, and EDFAs and dispersion compensators are used to improve the quality of the optical signal over the long distances considered. This setup gave the ability to test applications, traffic flow and latency [30]-[38] over various long distances similar to actual distances between cities in a typical core network [18].
In order to demonstrate end-to-end communication, two processing nodes were connected through an IP/WDM core network and a PON cell as shown in Figure 5, an IPTV Camera was connected to the first processing cell and streams live video throughout the processing cell, over the IP/WDM Core networks nodes, and to the OLT/ONU.

3. RESULTS

The end-to-end system connectivity was accomplished by connecting two processing nodes, an IP/WDM Core Network Nodes, and an OLT/ optical network unit (ONU). High quality real time video streaming using an IoT camera and an IPTV camera over a distance of over 110 km demonstrated continuous flow of traffic.

The ICMP protocol and route tracing were used to ensure proper routing and configuration of the network. ICMP signals were sent from servers on the all the nodes within the network with successful replies in every test resulting in 0% packet loss. A traceroute signal was sent from the first server in the processing cell to the last server in the other processing cell at the end of the system setup. The latency at each point was measured by
obtaining the round-trip time (RTT) of each hop. The traceroute signal was sent 10 times, each with 150 results. Figure 6 shows the 10 test iterations and the results of each hop’s average RTT. The end-to-end system has proven to have low latency, with RTT less than 2 ms (ranging from 0.1958 ms to 1.7619 ms) as shown in Figure 6, despite the traffic being relayed over long distances and diverse platforms. Figure 7 shows that there is on average a 0.7 ms delay between the core network and OLT while all other nodes maintained an average of 0.2 ms delay which is due to the number of nodes within the core network.

4. CONCLUSIONS
This paper provided an experimental evaluation of the performance of a proposed Service Centric PON based data centre architecture that is cost and power efficient. The performance was illustrated by using ICMP signals and video streaming. The NetFPGA boards for NIC communication facilitated the optical interconnections between servers while maintaining high speed and high data rate. In our previous experiment [19], 5 nodes were tested for latency, whereas in this paper 8 nodes were tested and the results showed that the increase in delay was insignificant when expanding the number of nodes at the data centre level.

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