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Performance Evaluation of Next-Generation Elastic Backhaul with Flexible VCSEL-based WDM Fronthaul

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Abstract *We experimentally demonstrate that 5G network stringent delay and bandwidth requirements can be satisfied adopting a novel optical network architecture, utilising flexible optical time slot switching, programmable optical interfaces and VCSEL-based WDM technologies, in a city-based field trial.*

Introduction

Emerging 5G networks require new network technologies to support the 5G key performance indicators (KPIs)[1] with the most important ones being high bandwidth and sub-millisecond end-to-end latency. To address these requirements, converged optical and wireless networks technologies are proposed to form a flexible transport infrastructure in the ongoing 5G-PPP project 5G-Xhaul[2]. This project proposes a new centralized radio access network (C-RAN) architecture supporting both backhaul (BH) and fronthaul (FH) functionalities. The FH services refer to operational services offered to the wireless network interconnecting Radio Units (RUs) with the centralised Base Band Units (BBUs) in support of the C-RAN solution.

In a 5G network, the combination of active and passive optical transport technologies can provide the required capacity and flexibility to provision both FH and BH services. Therefore, to address the high bandwidth and low-latency connectivity requirements, we propose a flexible hybrid active and passive solution that offers high bandwidth and low-latency. The time shared optical network (TSON) approach is considered for the active technology[3], and the passive solution adopts a wavelength division multiplexing (WDM) Passive Optical Network (PON)[4] adopting low-cost tuneable micro-electromechanical system (MEMS) vertical-cavity surface-emitting lasers (VCSELs), to provision jointly optical BH and FH services.

In this paper, we experimentally demonstrate that a 5G infrastructure deploying a suitable optical transport solution is able to support both FH and BH services. A bidirectional 10 GbE transmission is undertaken over a dark fibre ring of the Bristol City Network “Bristol is Open” (BIO) Infrastructure. Our experimental results showed that the additional latency provoked by the TDM-based reframing process in the TSON nodes, and the performance of tuneable MEMS-VCSEL can fulfil the stringent FH requirement in the field.

Backhaul and Fronthaul Architecture

Fig. 1 shows the TSON solution where two different type of nodes, namely TSON edge and TSON core nodes are illustrated. The TSON edge nodes are used to interface multiple technology domains (e.g., wireless, PON and data centres). TSON core nodes are used to switch optical frames to the wavelength selective output utilizing fast-optical switching technology (e.g., PLZT[3]). The WDM-PON provides flexible

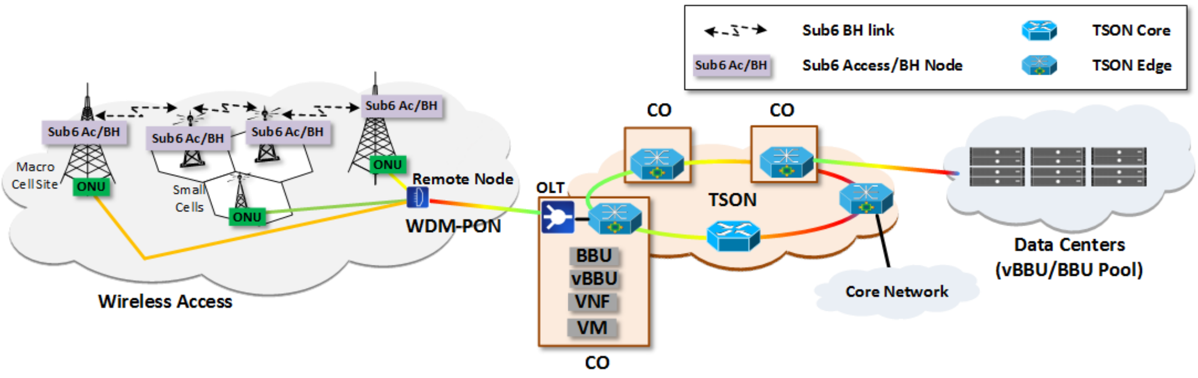

Fig. 1: The role of TSON and WDM-PON technologies in the 5G-Xhaul project

FH connections, between RUs at the antenna side and BBUs at the central office (CO), where the key component for a feasible low-cost implementation is the tuneable laser at the remote interface. Therefore, we propose adopting a MEMS-VCSEL at the optical network unit (ONU), which is capable of 10 Gbps transmission over up to 20 km single-mode fibre (SMF).

Testbed Setup and Implementation

Fig. 2 shows the integration of TSON and WDM-PON technologies for optical FH and BH services. In the TSON network, two nodes perform both ingress and egress functionalities based on the direction of the traffic. The TSON ingress node is responsible for receiving data traffic, and generating the time-sliced optical burst traffic based on the selected time-slice duration (e.g., 10µs). The TSON egress node reconstructs the original information. The TSON solution is implemented on the NetFPGA SUME platform. The default SUME FPGA board supports 4 optical small-form factor pluggable (SFP+) transceivers at 10Gbps line rate. In this demonstration, we used 3 SFP+ interfaces in each TSON node, two SFP+ (1310nm) for data and control traffic interfaces, and one SFP+ (1550.43nm) for interconnection between TSON nodes. A Software Defined Networking (SDN)-enabled TSON-control interface is supported to change flexible TSON functionalities (e.g., wavelength switching, time-slice duration, and variable bit rates) on the fly[5].

In the optical line terminal (OLT), a low-latency cross-connect switch not only converts the grey interface (1310nm) from the TSON egress port to the L-band DWDM light, but also flexibly assigns the connectivity of remote ONUs. For a proof of concept demonstration, only one bidirectional DWDM channel over the dark fibre of the city network is implemented, and the de-/multiplexer at the remote node (RN) is omitted.

As shown in Fig. 2, the prototyped ONU consists of one tuneable VCSEL SFP+ (Bandwidth10 Inc.) working in the C-band for the upstream link with a tuneable range of 13nm and 10Gb/s transmission capacity (Fig. 2 inset: optical spectrum of 16 channels), and the transponder interfaces between the grey light and C-band. The tuneable VCSEL is a much lower cost option than the ones used in other commercially available tuneable SFP+, due to its simpler tuning and testing (1 input instead of 3+ inputs used in tuneable edge emitters), as well as simpler epitaxy and fabrication processes. More details can be found in[6]. The module also has integrated an embedded communication channel for receiving the control signal from the OLT and responding to its commands to find the edge of the optical filter, and then fine tune the laser wavelength to the centre of the band. The much lower cost and power consumption of a VCSEL-based tuneable SFP+ make it highly suitable for the fronthaul and access networks.

To compensate for the chirp induced by the VCSEL, a dispersion compensating fibre (DCF) with chromatic dispersion factor of -339 ps/nm is used in the uplink regardless of transmission distances (i.e., 8, and 16 km), while the EDFA is used only for the transmission of 16 km. It is important to mention that the cost of EDFA and DCF can be shared among all ONUs, thus still remaining low-cost overall.

Experimental Results

For the experimental evaluation three different scenarios are considered. The first scenario includes both FPGAs and WDM-PON setups without the optical fibre (back-to-back). In the second and third scenarios, the proposed technologies are evaluated over the BIO dark fibre with 8km and 16 km of standard single-mode fibre (SSMF) and optical switches between RN and OLT to investigate the performance of FH

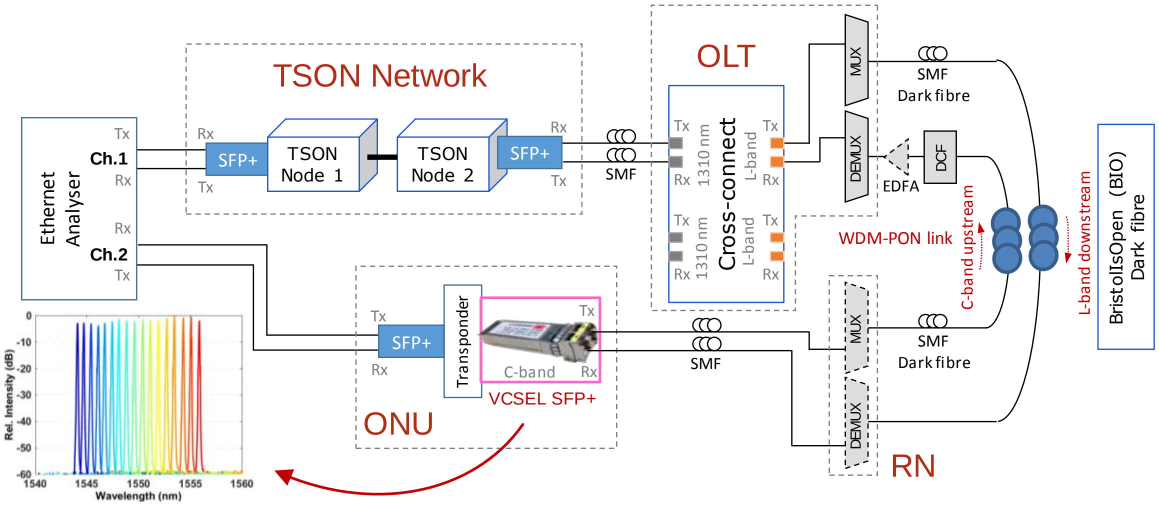

Fig. 2: Testbed configuration of TSON and WDM-PON Integration using BIO dark fibre

services (Fig 2). A traffic analyser generates/receives the Ethernet traffic to/from the NetFPGA NIC/ONU at 8.6 Gbps with fixed frames of 1500B length. The performance parameters under consideration include bit error rate (BER) and latency. The latency is defined as the time difference between arrival of a frame at the analyser, and its departure from the analyser.

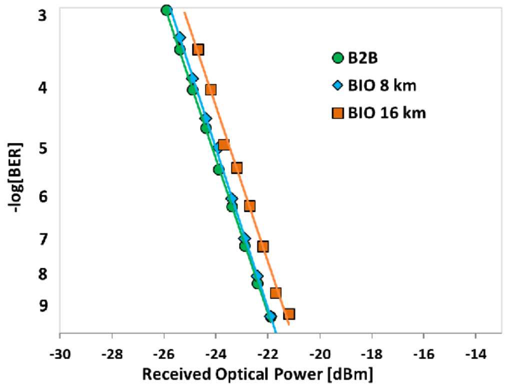

Fig. 3: Downstream BER measurements

Fig. 3 shows the downstream BER measurements as a function of received optical power at the MEMS-VCSEL SFP+ for the different considered scenarios. The BER curves shows that the penalty observed comparing the B2B performance to the case of 8 km of SSMF transmission over the BIO infrastructure is negligible. A penalty of < 1dB is observed for the case of 16 km transmission.

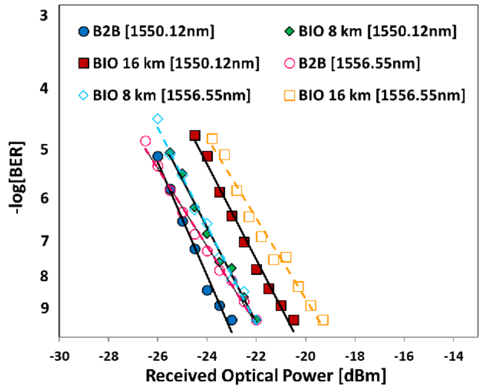

Fig. 4: Upstream BER measurements

Fig. 4 shows the BER curves for different upstream wavelengths (C-band) as a function of received optical power at the cross-connect switch, for the considered scenarios in the upstream direction. The BER performance of different upstream wavelengths appears slightly inconsistent, because in the experiment, the VCSEL wavelength has not been locked, leading to misalignments with respect to the DEMUX window. A 3dB power penalty is observed in the 16 km case, due to the increased noise level from the EDFA. Fig. 5 shows the upstream latency measurement of the scenarios considered. The upstream includes a DCF, which introduces an additional delay of around 19µs. About 33µs of the latency is measured within the FPGA, which includes physical and logic processing. Note that the delays can vary depending on the frame length. WDM-PON system (MUX/De-MUX, OLT, RN, ONU) latency is measured around 0.5µs. The remaining delay is the propagation delay in optical fibre depending on the length. Downstream delays are similar to upstream delays, but without the DCF contribution.

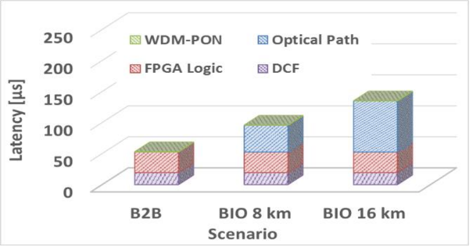

Fig. 5: Upstream Latency measurements

The measured latency in both downstream and upstream cases is lower than the latency budget defined in 3G-PPP TR 38.801. This indicates that combining active and passive technologies can help to meet latency requirements of FH services.

Conclusions

This paper experimentally demonstrated that flexibility in 5G networks can be achieved utilizing integrated active and passive optical technologies for transport. The results showed that frame-based optical network technology can help to meet high bandwidth and low latency 5G requirements integrating flexible VCSEL-based passive WDM technology. For the downstream scenario, negligible power penalty was observed in the BER measurements, for 8 and 16 km over the Bristol city dark fibre infrastructure. For the upstream case, penalties <3dB were obtained, for the 8km and 16km of dark fibre and for different wavelengths.

Acknowledgements

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