Experimental Real Time AMCC Implementation for Fronthaul in PtP WDM-PON

Zakaria Tayq[(1,2)], Luiz Anet Neto[(1)], Philippe Chanclou[(1)], Christelle Aupetit-Berthelemot[(2)]
[(1)] Orange Labs Networks, 2 Avenue P.Marzin, 22300 Lannion, France, zakaria.tayq@orange.com
[(2)] XLIM, UMR CNRS 7252, 16 rue d'Atlantis, 87068 Limoges CEDEX, France

Abstract *A real-time pilot tone implementation allowing fronthaul monitoring and wavelength tunability in WDM-PON systems is experimentally demonstrated. The obtained results show transmission of a 128 kb/s control signal with minor impact on CPRI.*

Introduction

In the coming years, a fast evolution of fixed and mobile networks is expected. With the massive deployment of Fiber-To-The-Home (FTTH) networks and the evolution of mobile networks with small cells deployment, it becomes primordial for telecom operators to mutualise their optical access infrastructure in view of a better fixed-mobile convergence [1].

Concerning the optical infrastructure used for mobile data transport, we witness today the emergence of the new Cloud and Virtual Radio Access Network (C&V-RAN) architecture [2], based on the centralisation of the Base Band Units (BBU) thanks to a new network segment called fronthaul. The latter is the link between the antenna sites, where the Remote Radio Heads (RRH) are located, and the BBU hotel, where all signal processing on the radio signal occurs. Presently, it uses a digital radio over fiber (D-RoF) interface e.g. the Common Public Radio Interface (CPRI) [3].

The second Next Generation of Passive Optical Networks (NG-PON2) expects such convergence in the access network. In this context, two flavours are envisaged using the same fiber infrastructure: a point-to-multipoint architecture using Time and Wavelength Division Multiplexing (TWDM) PON for residential access and a Point-to-Point (PtP) WDM-PON approach for mobile backhaul, fronthaul and business services.

The wavelength tunability and the transport of monitoring data are expected in WDM-PON with the implementation of an out-of-band control channel as indicated by the ITU-T G.989.2 standard [4]. In fact, this channel, called Auxiliary Management and Control Channel (AMCC), will transmit wavelength assignment and allocation information as well as Operation Administration and Management (OAM) data. It will be inserted in each wavelength for the upstream and downstream. AMCC can be implemented either by a baseband over modulation or by a radio frequency pilot tone (PT), which is the subject of this paper.

In the standard, a 500 kHz RF carrier is modulated by 128 kbit/s NRZ (Non Return to Zero) signal with a modulation index of 10%. In [5], the authors proposed an offline AMCC implementation for WDM-PON using a Mach-Zehnder Modulator and obtained quite promising results. It was confirmed that it was feasible to insert a 128 kb/s pilot tone at 500 kHz with 10% modulation index on a fronthaul link with negligible impact on the CPRI.

In this paper, an extended study considering the implementation issues is proposed. A real time transmission of AMCC over a 20 km fronthaul link is carried out using a Directly Modulated Laser of a commercial Small Form factor Pluggable (SFP). Different measurements are carried out to verify the performances of the AMCC and to evaluate its impact on the CPRI and radio mobile signal integrity.

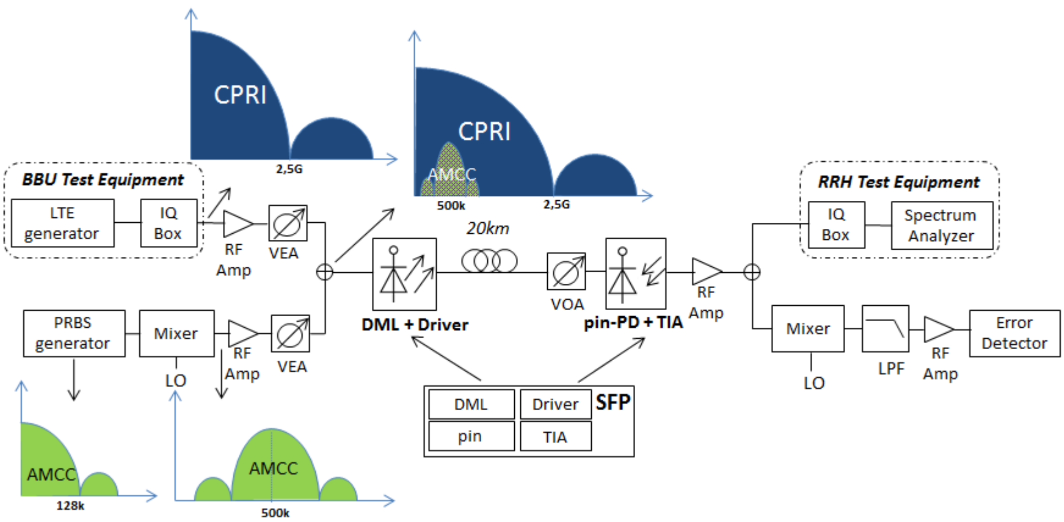

Fig. 1: Experimental setup

Experimental setup:

Figure 1 shows the experimental setup. At the transmission side, a signal generator is used to generate a 20 MHz LTE carrier using standardized test model E-TM3.1 [6]. This signal is converted to CPRI (sampling + quantization + coding) using an IQ box.

A Pseudo Random Binary Sequence (PRBS) generator is used to emulate the AMCC transmission using a 2^7-1 length sequence. This low frequency signal (128 kb/s) is up-converted using a mixer and a Local Oscillator (LO) at 500 kHz. Both AMCC and CPRI signals are separately amplified and gradually attenuated with a Variable Electric Attenuator (VEA) so that the ratio between the signals peak-to-peak voltage can be changed. The signals are then summed up with a power combiner. The obtained signal is fed to a driver then to a Directly Modulated Laser (DML) diode operating at 1590 nm (fixed wavelength) and 0 dBm before transmission over 20 km standard single mode optical fiber. The received optical signal is detected by a pin-photodiode then amplified with a Trans Impedance Amplifier (TIA). The used laser, photodiode, driver and TIA are embedded in a commercial SFP module as shown in Figure 1. The received RF signal is amplified then halved with a power splitter. A part is fed to the RRH test equipment composed of an IQ box for CPRI to LTE conversion and a Spectrum Analyser for LTE analysis. The second part is down converted then low-pass filtered by a 250 kHz filter to remove the CPRI high frequency components and potential harmonics and intermodulation products being generated by non-linear mixers. After filtering, the signal is amplified before performance evaluation.

Experimental results:

We focus our analyses on three main performance indicators: Bit Error Rate (BER), Error Vector Magnitude (EVM) and jitter. We started by investigating the BER variation of both CPRI and AMCC signals as a function of the relative modulation index, the latter being

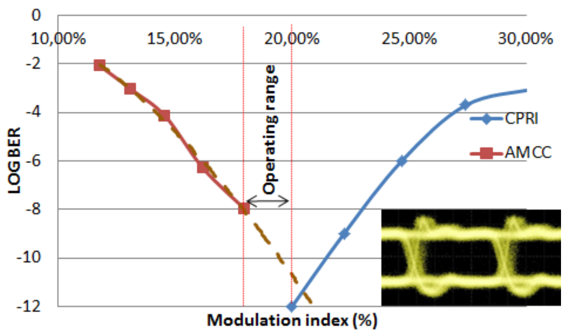

Fig. 2: CPRI and Pilot Tone BER performance for different modulation index and optical eye diagram at 20% modulation index

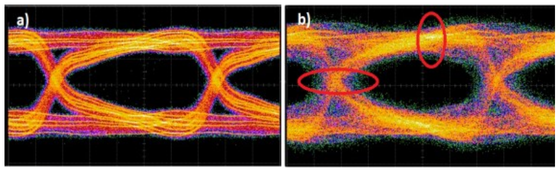

Fig. 3: Eye diagrams of received CPRI 3 with (a) and without (b) pilot tone transmission.

defined as the ratio of the peak to peak voltage value of the AMCC with respect to the CPRI signal [4]. The results for a CPRI 3 (2.45 Gb/s) and a 128 Kb/s AMCC transposed to 500kHz are depicted in figure 2 for different relative modulation indices.

Figure 2 shows that error free AMCC and CPRI transmissions ($\mathrm{BER} \leq 10^{-8}$ and $\mathrm{BER} \leq 10^{-12}$ respectively) could be obtained for modulation indices between 18% and 20%. This range is higher than the value adopted in the standard and the one found in [5]. We believe that such difference can be attributed to the low sensitivity of the equipment used for the AMCC BER measurement and to the fact that the used driver and TIA (embedded in the commercial SFP) are not designed for the amplification of low frequency signals.

In order to evaluate the impact of introducing the AMCC in a fronthaul link, we fix the relative modulation index to an optimal value of 20%. Figure 3 displays the obtained eye diagrams at the input of the RRH test equipment (after opto-electrical conversion by the SFP PIN) at 2.45 Gb/s with and without the AMCC signal. Some noise on the zero and one levels can be noticed as well as some jitter due to the introduction of the control signal.

Figure 4 shows the impact of the AMCC signal on the LTE EVM while varying the Received Optical Power (ROP) at the input of the PIN photodiode. Measurements are carried out for CPRI 3 and 6 (2.45 Gb/s and 6.14 Gb/s respectively) without the AMCC, with a 128 kb/s AMCC up-converted to 500 kHz and with a 128kb/s AMCC up-converted to 1 MHz. 64 QAM modulation is used for LTE transmission since it has the most stringent EVM requirement (9 %) according to the 3GPP standard [6]. We notice a penalty of 0.85 dB in the optical budget when inserting the AMCC on CPRI 3 and 1.35 dB for CPRI 6 for a fixed EVM of 0.06%. We also

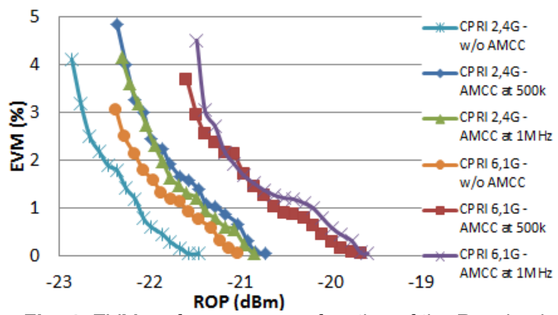

Fig. 4: EVM performance as a function of the Received Optical Power (ROP)

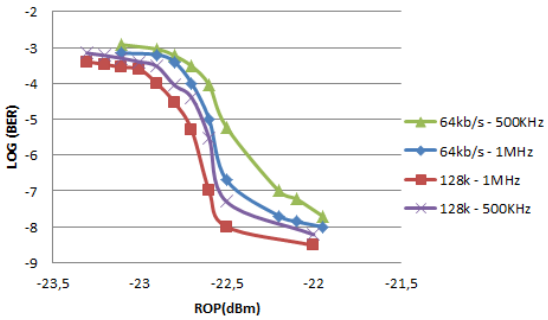

Fig. 5: BER performance as a function of the received optical power

observe very similar performances when the AMCC is at 500 kHz and 1 MHz. Figure 4 also shows that an optical budget of up to 22 dB can be obtained before achieving 3% EVM which allows for a 6% extra margin with respect to the 3GPP standard.

We also evaluated the AMCC performance in terms of BER for 128 kb/s and 64 kb/s bit rates and for an up-conversion to 500 kHz and 1 MHz as depicted in Figure 5. We notice a better performance at 128 kb/s which we believe is due to the filter characteristics at the receiver side. On one side, by transmitting at 64 kb/s and using a 250 kHz low-pass filter at the receiver, we keep more lobes of the AMCC signal spectrum, which allows having a more squared time-domain signal, thus a better transmission. However, it also implies that more energy of the CPRI signal is contained inside the filtered AMCC, which, on the other side, degrades performances. The shape of the obtained BER curves can be explained by the presence of a limiting TIA in the SFP, which causes a sudden BER deterioration. We also observe a slight performance improvement at 1 MHz certainly because the AMCC channel is better positioned with respect to our components frequency responses.

Finally, we evaluated the jitter introduced in the CPRI at 2.45 Gb/s upon the insertion of the AMCC. The presence of a low frequency signal in the CPRI prevented us from using the accurate dual-Dirac jitter estimation approach [7]. An alternative method was then carried out by means of an analysis of the CPRI eye diagram. In order to verify the reliability of the eye diagram approach, we first performed a reference measurement without the AMCC and compared it to the dual-dirac approach. We measured 132 mUI with the dual-Dirac model and 148 mUI with the eye diagram which validated our method. Table 1 shows the measured jitter on the CPRI at the input of the RRH test equipment with and without AMCC. A significant amount of jitter is introduced upon AMCC insertion. Nevertheless, the maximum jitter value defined by the CPRI specification is

Tab. 1: Jitter measurement on the CPRI3 eye diagrams with and without AMCC

Jitter at Receiver w/o AMCC	Jitter at Receiver with AMCC	Maximum value (CPRI specification) [3]
148 mUI	406 mUI	650 mUI

still respected. We must notice that lower jitter values could be obtained after filtering out the AMCC from the CPRI signal by means of a band-stop filter. However, the impacts of such filtering on the CPRI performances would have to be evaluated.

Conclusions

In this paper, we experimentally demonstrated a real time AMCC implementation using a commercial SFP for fronthaul transport over WDM-PON. Performance measurements were carried out on CPRI and AMCC signals. An optimum relative modulation index range between 18% and 20% was found allowing for error-free transmission for both CPRI and AMCC. Also, an optical budget of up to 22 dB could be demonstrated using CPRI at 2.45 Gbit/s with an additional 6% margin on the recommended EVM values, which is compatible with the optical path loss class L1 based on a range of 8 to 17dB [8]. The obtained results are very promising and show that pilot tone implementation can be done with respect to both 3GPP and CPRI specifications.

Acknowledgements

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References

[1] S. Gosselin, A. Pizzinat, X. Grall, D. Breuer, E. Bogenfelf, J. Gijon, A. Hamidian, N. Fonseca, "Fixed and Mobile Convergence: Which Role for Optical Networks?" Proc. OFC (2015)

[2] A. Pizzinat P. Chanclou; T. Diallo; F. Saliou, "Things you should know about fronthaul" Proc ECOC (2015)

[3] CPRI Interface Specification, v. 7.0, October 9th, 2015

[4] ITU-T Recommendation G.989.2, "40-gigabit-capable passive optical networks (NG-PON2): Physical media dependent (PMD)"

[5] K. Honda; T. Kobayashi; T. Shimada; J. Terada; A. Otaka, "WDM Passive Optical Network Managed with Embedded Pilot Tone for Mobile Fronthaul" Proc ECOC (2015)

[6] 3GPP TS 36.141: E-UTRA BS conformance testing, Rel. 10, V10.1.0, 2011.

[7] "Jitter Analysis: The dual- Dirac Model, RJ/DJ, and Q-Scale", Agilent Technologies (2004)

[8] ITU-T Recommendation G.989.2 Amendment 1, Annex C