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Multi-channel LTE-over-Fiber system based on 850nm VCSEL and SSMF for low cost, low consumption Front-Hauls

Jacopo Nanni (1), Luis Fernández (1), Muhammad Usman Hadi (1), Carlos Viana (3), Zerihun Gedeb Tegegne (2), Jean-Luc Polleux(2,3) and Giovanni Tartarini(1)

[1]*DEI-University of Bologna, Bologna, Viale del Risorgimento 2, Italy*
[2]*University of Paris-Est, ESYCOM, ESIEE Paris, France, 2 boulevard Blaise Pascal, Noisy-le-Grand, France*
[3]*ICON-Photonics, 2 bis Rue Alfred Nobel, Champs-sur-Marne, France*
e-mail : jacopo.nanni3@unibo.it

ABSTRACT

A Multi-channel LTE transmission on a Radio-over-Fibre (RoF) system realized with low cost and low consumption 850nm Vertical Cavity Surface Emitting Laser (VCSEL) and Standard Single Mode Fibre (SSMF) is proposed in the framework of wireless networks front-haul links. The performances are evaluated through the Error Vector Magnitude (EVM) comparing different distances, channels employed and modulation formats using the carrier aggregation nominal channel spacing for 20 MHz bandwidth LTE signals. The potentiality of this link is then highlighted by the maximum length achievable according to the LTE standard for 64-QAM, 256-QAM and 1024-QAM modulation formats, for which the maximum length results to be greater than 2 Km, 1 Km and 100m, respectively.

Keywords: Radio-over-Fibre, Vertical Cavity Surface Emitting Lasers, Single mode fibre, Wireless networks,

1. INTRODUCTION

The Radio-over Fibre (RoF) technology has been recognized in the recent years as one of the most competitive solutions for current and next generation wireless networks front-haul (FH) infrastructure. Indeed, mobile networks aim to be much denser in the future in order to increase the overall capacity and to achieve an optimization of resources and power consumptions, and the RoF technology is suitable to achieve these goals. The principle of the RoF-based front-haul architecture is shown in Figure 1 in which RoF is used to connect a centralized unit to many Radio Resource Heads (RRHs) which act as radio access point for the user equipments (UEs). Then all the centralized units are connected to the central network.

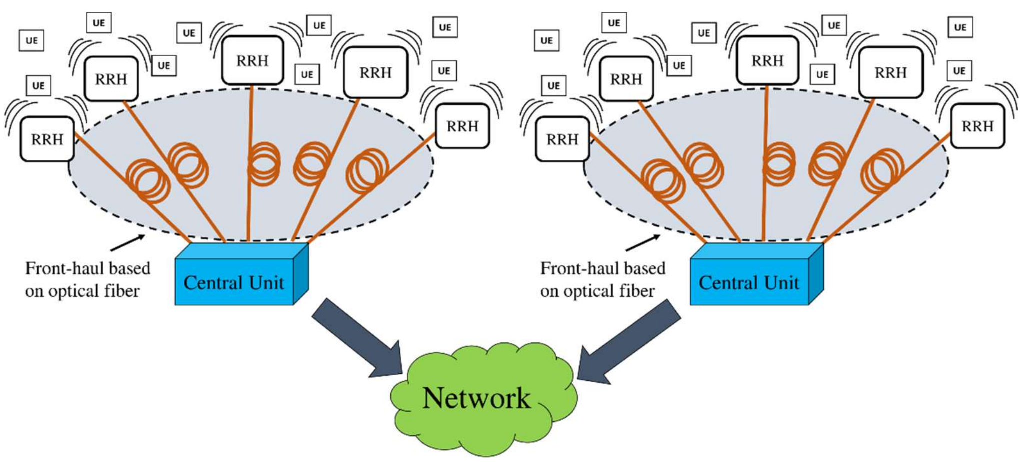

Figure 1. Example of Front-Haul architecture employing RoF links. The central unit is connected via RoF links to many Radio Resource Heads (RRHs) which represent the access points for the mobile user equipment (UE).

Indeed, to extend and spread the network in this way it is necessary to keep the cost and consumption of each FH link as low as possible. Toward this direction, the Analog RoF (A-RoF) architecture nowadays is the most competitive technology in terms of ease of deployment, cost and consumptions compared to other non-analogue techniques [1] such as for example the DSP-Assisted RoF [2] or the Digital RoF (3).

It has been recently shown that to decrease power consumption and cost of such links, 850nm Vertical Cavity Surface Emitting Lasers (VCSELs) can be used instead of Distributed Feedback Laser in the framework of different applications such as wireless networks [4], digital transmission for datacentres [5] or machine learning detection [6]. The use of VCSEL is generally combined to the use of Graded-Index Multimode Fibbers (GI-MMFs) [5-6], rather than Plastic Optical Fibres (POF) [7], used nowadays only for very short distance applications mainly because of the bandwidth/length trade-off of such fibres. However, the use of Standard Single Mode Fibres (SSMFs) is recommended among all other fibre typologies. In particular, the possible re-use of many infrastructures based on SSMF already installed for applications in 2nd and 3rd window could improve the cost-effectiveness of such links, together with the low manufacturing cost and limitations of the SSMF compared to the GI-MMF and POF. In the recent years 850nm SSMF-based link have been investigated and considered for applications regarding both wireless networks [8,9] and digital transmissions [10] where many techniques have been proposed in order to reduce the undesired effects produced by the bi-modal propagation at 850 nm in SSMF.

The most recent works concerning this topic have shown that it is possible to achieve kilometre-range link distances employing a single mode VCSEL and a short span of a small diameter fibre which acts as pre-filter [11,12]. This filter helps to reduce the impact of the higher order mode (LP_{11}), providing a mitigation of multimodal behaviour phenomena such as intermodal dispersion and modal noise [13] and improving significantly the signal transmission quality. Extending these achievements, the presented work shows the concrete feasibility of a multi-channel LTE transmission on an A-RoF system based on 850nm VCSEL and SSMF. The dependence of the quality of the received signal on design parameters like link length, modulation format and the number of channels transmitted will be put into evidence considering a value of 100MHz for the maximum occupied signal bandwidth.

2. EXPERIMENTAL SETUP AND DESCRIPTION OF THE A-ROF LINK PROPOSED

The experimental setup is shown in Figure 2a. The A-RoF link proposed in this work is designed to operate at a carrier frequency of 750 MHz and is composed on the electro-optic transmitter side of an 850nm single-mode VCSEL already coupled with a short (~1 meter) pigtail of SSMF provided by Optowell. The pigtail is connected to a span of truly single mode fibre at 850nm (named 780HP) characterized by about 5 μm core diameter which even at 850nm allows the propagation of the only LP_{01} mode. A longer SSMF span of length L ranging from 100 m to 2 Km, is connected to the 780HP which is exploited as a pre-filter, exciting mostly the fundamental mode of the SSMF.

It has been shown in [12,13] that this solution improves significantly the quality of the transmission in case of single channel signals, especially for such carrier frequencies that would be otherwise suppressed by the interference of LP_{01} and LP_{11} modes. The pre-filter in fact can mitigate the phenomenon of intermodal dispersion producing a higher flatness in the modulation response of the system. Figure 2b shows an example of received spectrum with and without the use of 780HP for 300m of SSMF transmitting 5 LTE channels centred in 750MHz.

As receiver, a GaAs PIN photodiode with a responsivity of about 0.6 A/W is employed followed by a Low Noise Amplifier (LNA) characterized by 38dB of Gain and a noise figure of about 2-3dB at the considered frequency (750 MHz). The SM VCSEL utilized has a threshold current value of about 2 mA and a saturation current around 5 mA (see LIV curve in figure 2c). The biasing point chosen is 4.5 mA which results to give the best performance in terms of EVM for the optical back-to-back link (about 1 meter of SSMF fibre span). The laser impedance matching at 750 MHz is around 50 Ohm.

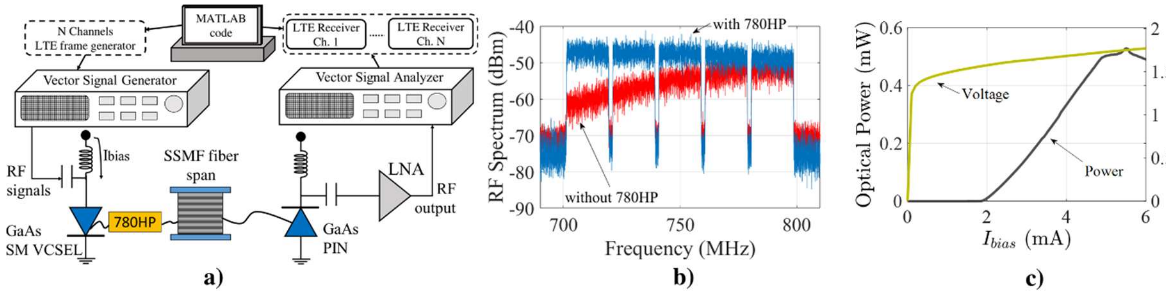

Figure 2. (a) Experimental setup used to test the multichannel transmission on the A-RoF link considered. (b) Example of intermodal dispersion mitigation by using the 780HP filter in case of 5 Channels aggregated signal transmitted over 300m of SSMF. (c) LIV curve of the SM VCSEL employed.

The multi-channel transmission is performed by using a home-made MATLAB code which generates baseband samples of N independent Frequency Division Duplex (FDD) LTE channels before overlapping and sending them to a Vector Signal Generator for up-conversion and consequent transmission to the RoF link under test. At the receiver side the signal is captured by a Vector Signal Analyzer and each channel is analysed separately by the MATLAB code for computation of the performances in terms of Error Vector Magnitude (EVM). Then, an average EVM among the channel is taken named in the following paragraphs as EVM_{AVG}. The EVM measurements is considered related to the Physical Data Shared Channel (PDSCH). The modulation format considered are 64, 256 and 1024 QAM according to the release 15.2 of the standard ETSI TS 136.211.

The channels transmitted are considered with the same bandwidth of 20 MHz and are spaced by the carrier aggregation nominal spacing defined in the release 15.02 of ETSI TS 136.141, considering a maximum occupied bandwidth of 100MHz. The Peak-to-Average Power Ratio (PAPR) of each generated channel is about 10-11 dB while the PAPR of the sum of 5 channels results to be around 13-14 dB.

3. EXPERIMENTAL RESULTS

Experimental results are shown first in figure 3a in which the behaviour of EVM_{AVG} is presented with respect to the total RF input power injected into the laser for the optical back-to-back configuration. The figure compares the case of single channel transmission and the case of 5 channels transmitted to identify a region of operation of the total input RF power to inject into the laser. From figure 3a it can be seen that an optimum range of operation for the laser in which the EVM_{AVG} reaches its minimum ranges in both cases from -12 dBm to -9 dBm. For this reason, in the following measurements the value of -10 dBm has been utilized as total input RF power injected into the laser. The measurements taken utilizing this value of RF power at different SSMF length are then shown in figure 3b, where an increase of EVM_{AVG} can be observed in passing from single channel to 5 channels transmission.

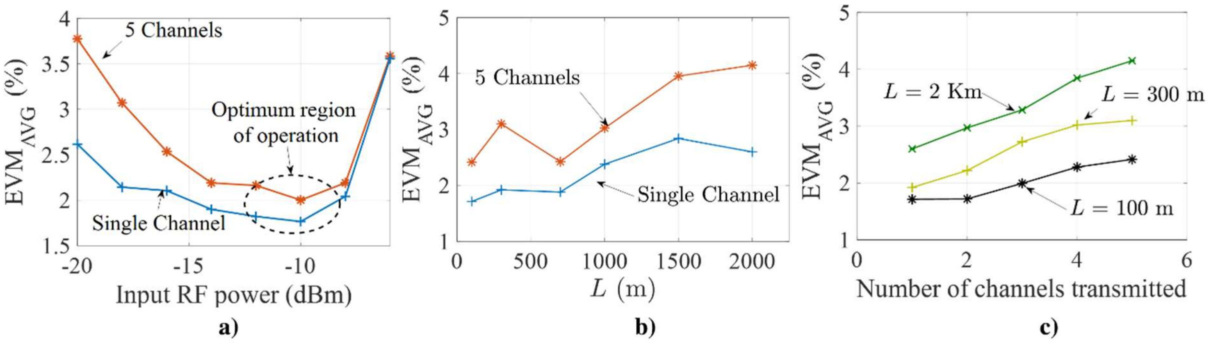

Figure 3. (a) Characterization of the optical back-to-back varying the total RF input power for the case of single channel and 5 channels transmitted of 20MHz bandwidth. (b) EVM_{AVG} behavior as function of the length for single channel and 5 channels transmission. (c) Dependence of EVM_{AVG} on the number of channels transmitted for different SSMF length.

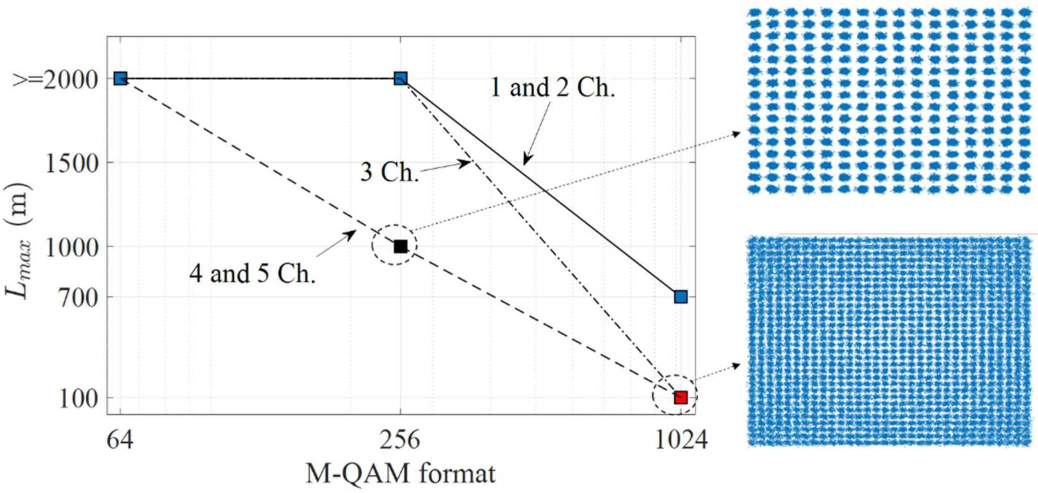

Figure 4. Estimated maximum length achievable with the system proposed for different modulation format and number of channels transmitted.

The behavior of EVM_{AVG} as function of the number channels is more evident in figure 3c considering as parameter the SSMF length. Indeed, increasing the number of channels transmitted an increment of EVM_{AVG} takes place independently on the SSMF length. Figures 3b and 3c allow then to grasp a quantitative overview on the dependence of the performance of the A-RoF link considered on both number of channels and fiber length.

To put in evidence the practical use of the A-RoF link proposed, a final evaluation of the maximum distance achievable depending on modulation format and number of transmitted channels is presented.

Figure 4 shows the maximum link distance $L_{max,x-QAM}$ for which the x-QAM modulation format transmission is reachable. The EVM limit considered is 2.5% for 1024-QAM, 3.5% for 256-QAM and 8% for 64-QAM according to the release 15.3 of the standard ETSI TS 136.104.

As main results it can be appreciated that the A-RoF link proposed is able to transmit 5 LTE channels for maximum distances of SSMF of $L_{max,64-Q} \geq 2Km$, $L_{max,256-Q} \simeq 1Km$ and $L_{max,1024-QAM} \simeq 100m$.

4. CONCLUSION

This paper proposed a low cost and consumption analogue radio-over-fibre link based on 850nm VCSEL and SSMF for the aggregated multi-channel front-haul transmission of LTE signals in the frequency band of 750MHz.

The system has been characterized for different lengths of transmission, number of channels and modulation formats. In order to avoid the problems of intermodal dispersion and modal noise, a pre-filtering based on the use of a short patch-cord of 5 μm fibre diameter (780HP) is exploited. An evaluation of maximum distances achievable was presented for different modulation formats and number of channels employed. In particular, it has been shown that it is possible to transmit 5 aggregated channels for more than 2Km with 64-QAM, 1Km for 256-QAM and 100m for 1024-QAM compliantly with the LTE standard.

This system proposed is hence considered suitable for current and next generation front-haul links in very dense networks with a high potential perspective of implementation in future 5G infrastructure.

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