Digital Radio over Fiber System in the NG-PON2 context

Rosinei S. Oliveira[1,2].; Diogo F. R Viana[3]; Mario Lima[3].; Carlos R. L. Francês[2].; Antonio Teixeira[3].;
João C. W. A Costa[2]
[1]Federal University Western of Pará, Mendonça Furtado A., 2946, PC 68040-470, Santarém, PA, Brazil
[2]Federal University of Pará, Augusto Corre A., 01, PC 66075-110, Belém, PA, Brazil.
[3]Instituto de Telecomunicações, CP 3810-193, Campus Universitário de Santiago, Aveiro, Portugal
[1,2]{nei, rfrances, jweyl}@ufpa.br
[3]{ diogo.viana, mlima, teixeira }@ua.pt

***Abstract*— The current trends on traffic and mobile user's growth is pushing the capacity of the current networks to the limit, which has led telecommunication operators to expand their investment in infrastructure. In this context, centralized RAN (C-RAN) comes with an innovative solution for the changes that will occur in the network. C-RAN shifts all the complex functionalities from the base stations (BS) to the central office (CO). A new segment called fronthaul connects the base band unit (BBU) with the remote antenna over a digital radio over fiber (DRoF) transmission based on the common public radio interface (CPRI). In this work we propose and investigate, by means of simulation, the performance of the low cost DRoF system in several contexts: single channel and in coexistence scenario. To meet this goal, we first investigate the key aspects of DRoF in an isolated transmission and next we proceed with a coexistence scenario based on the ITU-T G.989 standard (NG-PON2). The results show that the DRoF system is compatible with a NG-PON2 with respect to the wavelength plan and bandwidth requirements.**

***Index Terms*—** C-RAN, Digitalized Radio-over-Fiber, TWDM-PON, NG-PON2.

I. INTRODUCTION

The next generation of mobile networks needs to meet the exceptional bandwidth demand expected for the coming years. Recent studies predict that in 2020 networks should be prepared to support an increase of up to 1000 times of total traffic compared to what is currently available [1]. Services such as ultra-high definition video streaming, online gaming, machine-to-machine communications and cloud computing are examples of bandwidth hungry applications that are fast becoming an essential part of consumer's lives. This traffic consumption is mainly due to the growing number of wireless devices that are accessing mobile networks, it was estimated that the number of connected mobile devices exceeded the world's population [2]. In average, is reported that the global end user traffic will grow up 21% from 2013 to 2018, while for the same period of time mobile traffic has a growth perspective of 61% [3].

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To handle this continuous need from increasing in traffic demands, the telecommunication operators have been exploring and deploy new technologies and network configurations to improve their end user’s experience. At present, Long-Term Evolution Advanced (LTE-A) is the main solution in the fourth generation of wireless access cellular technology. According to specifications a minimum of 1 Gbit/s is expected; however is possible reaching up to 10 Gbit/s in base stations (BS) with multiple sectors [4]. Although the 5th generation of mobile networks (5G) is still in research and debate, in the close future it will be introduced. The evolution of 5G is driven by important factors such as: higher number of simultaneously connected devices, better coverage, higher spectral efficiency, lower latencies, lower battery consumption, and others [5]. However, conventional microwave links connecting the BS with the core of the network cannot provide enough bandwidth to support those transmission rates and scenarios, which represents a big challenge from the operator's view. Connecting the antenna with the backbone over fiber links can solve this gap. This will change the traditional mobile network infrastructure, which also has forcing operators to embrace new solutions to improve the capacity of the system and to reduce its costs, mainly in radio access network (RAN). Nowadays, a new concept of RAN has attracted considerable interest from the telecommunication operators This concept is known as centralized RAN (C-RAN) and in comparison with a classic BS, this comes out with an innovative architecture where all the RAN functionalities are executed in the central office (CO), while the base station (BS) is responsible for executing less complex functions which bring reduced costs, improved performance and fixed/mobile convergence [6]. The connection between CO and BS is accomplished through digital radio over fiber (DRoF) transmission based on the common public radio interface (CPRI) [7]. However, the optical link requires a high bandwidth due to the digitalization process, which from the implementation point of view represents one of the major challenges.

To mitigate this requirement, a low cost DRoF system in terms of the bandwidth is proposed and investigated in two different contexts. In the first scenario, an overview with respect to key concepts, benefits and challenges involving DRoF transmission is conducted. Subsequently, DRoF transmission will be investigated in coexistence context, where its performance is compared with analog transmissions in the full NG-PON2 standard performed by legacy systems, GPON and XGPON, as well as newly standardized TWDM-PON technology. The total compatibility with all those technologies is ensured on a wavelength plan that ensures the total compatibility with all those technologies.

II. NEXT-GENERATION OPTICAL ACESS TRENDS

One of the biggest changes due to the integration of optical and wireless networks will occur on the radio access network (RAN). A new architecture of centralized control (C-RAN) has been proposed on the literature [6]-[11]. Unlike traditional models, in which the base band unit (BBU) and the remote radio head (RRH) are in the same location, in the C-RAN architecture these devices are located in different places as shown in Fig. 1. All complex functionalities that require more processing capacity and power consumption are executed at the BBU located inside the Central Office (CO), while the RRHs are placed on the antenna itself and are basically responsible for the functions of signal reception, amplification and A/D conversion. At the fronthaul, the connection between the BBU and RRH is performed through a radio interface similar to the common public radio interface CPRI or open base station architecture OBSAI [12]. In both cases, the digital radio over fiber (DRoF) transmission is use.

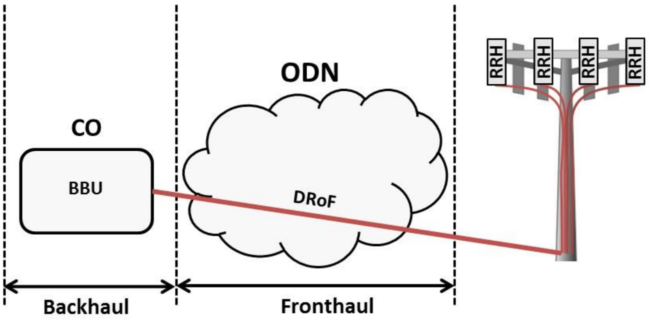

Fig. 1. C-RAN architecture

Radio over fiber systems has long been viewed as a potential solution to provide high data rates and to reduce energy consumption, especially in the base station [13]-[15]. On an analog RoF transmission, the information is transported over optical fiber by modulating the light with the radio in analog domain. On the other hand, DRoF system uses analog-to-digital converters (ADC) at the transmitter and digital-to-analog converters (DAC) at the receiver side, as such, all the transmission is to be performed in digital domain [16][17]. With respect to the signal transmission, analog RoF link suffers from intermodulation distortions (IMD); furthermore it is susceptible to fiber chromatic dispersion and other impairments from analog communication systems, which reduce the distance to a few kilometers. However, in DRoF system, the sampled digital signal minimizes the nonlinear effects originated from the optical-to-electrical (O-E) conversion presented on the analog transmission allowing the system to maintain its dynamic range independent from the fiber length, until the received signal goes below the sensitivity of the link.

The transmission of radio signals over fiber has attracted particular attention for using unlicensed millimeter-wave frequencies [14] However, considering millimeter-wave transmission with CPRI protocol the challenge is greater because the viability of the system is strictly limited to the ADC sampling frequency. To overcome this limitation, ADCs with high sampling frequencies have been proposed (40 GS/s) [18], however devices working in this operation range has a high power consumption and cost. In order to avoid considerably high sample rates, at the converter components, down conversion techniques of the RF signal can be used to relax the ADC/DAC sampling requirements [19].

The usage of the C-RAN architecture allows a cost reduction for the carrier due to the associated low cost of the RRH implementation compared to other traditional architectures. Sharing the same BBU with multiple RRH will also bring significant advantages in terms of energy consumption, which makes the C-RAN a green solution. Due to these advantages, RRH can be implemented not only for new technologies, such as LTE and LTE-A, but also for existing technologies in traditional infrastructures such as 2.5G and 3G. Depending on the technology, different rates are required at the fronthaul for the connection between the BBU and RRH. Considering CPRI protocol, the fronthaul segment must be capable of supporting rates up to 10 Gbit/s. Thus, the bandwidth requirements at the optical distribution network (ODN) represent one of the major challenges on the C-RAN implementation and needs to be investigated.

Passive optical network (PON) is the most used solution due to its low cost, but not all standards are supported at the fronthaul, because of the bandwidth required by the new technologies such as LTE-A. The G-PON standard [8] offers maximum rates of 2.5 Gbit/s. The XG-PON1 standard is capable of attending only the downstream demand because the upstream transmission is limited to 2.5 Gbit/s while the downstream supports rates of 10 Gbit/s. On the other hand, the last version of XG-PON (XG-PON2) offers symmetric rates of 10 Gbit/s. More recently, the ITU-T standardized the NG-PON2 [8], which brings significant improvements to the bandwidth capacity compared to the previous PON generation standards.

To implement a NG-PON2, the TWDM-PON hybrid technology which uses time division multiplexing (TDM) and wavelength division multiplexing (WDM), was selected as first option. In each optical line termination (OLT), this technology multiplexes 4 to 8 channels of 10 Gbit/s, capable of offering aggregated rates up to 40 Gbit/s, and optionally 80 Gbit/s. In terms of bandwidth, TWDM-PON complies with the speeds required by the CPRI, however the variable jitter delays and latencies from the TDM-PON in upstream transmission make the use of C-RAN a challenge [20][21]. To overcome this problem, Point-to-Point WDM (PtP WDM) can be used as optional solution, enabling NG-PON2 to meet demanding operator requirements for fronthaul services since the characteristics of the WDM are favorable due to lack of statistical multiplexing and due to the stringent requirements on latency and delay. However, as mentioned, the focus of this paper is the investigation of the radio digital transmission used by the CPRI in the converging context with emphasis on the bandwidth requirements necessary to support the transmission that can also be attended by the ONU from the NG-PON2 technology.

III. SIMULATION SETUP

A. Radio over Fiber Systems

The VPItransmissionMaker simulator [22] was used for the systems' design. A macro view of the analog and digital systems are shown in Fig. 2 and Fig. 3, respectively. In other work we have

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demonstrated the advantages of digital over the analog [23][24] in differents scenarios, however in this paper we compare the performance of the two transmissions in the convergence context. In analog intermediate frequency (RoF-IF), Fig. 2, from the central office (CO) to base station (BS), one 16-QAM RF signal with a 5 GHz carrier frequency is down-converted to intermediate frequency (IF) of 400 MHz, by means of a local oscillator (LO) at 4.6 GHz, and extracted with a bandpass filter of 400 MHz bandwidth. Hereafter, the signal is modulated externally with a MZM in an optical carrier sourced by a distributed feedback (DFB) laser and transmitted over a standard single mode fiber (SSMF). At the BS, one avalanche photo diode converts the optical signal to electrical domain which is up-converted to original frequency (5 GHz) using a LO at 4.6 GHz. To obtain large range of comparison, in this paper is also used RF analog signal (RoF-RF) in which the process of generation and detection of the signal is the same described before, however in this scenario the downconversion technique isn't used. In other words, the signal is sent in the original frequency (5 GHz).

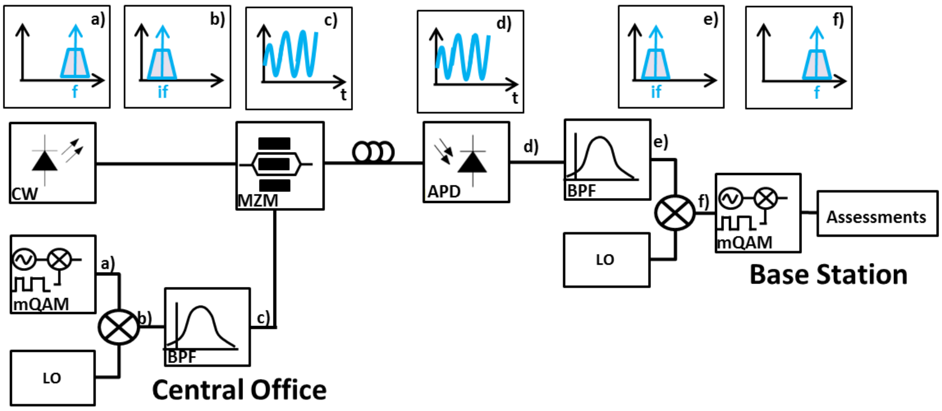

Fig. 2. RoF schematic simulated where the letters illustrates: Original carrier frequency (a); intermediate frequency after down conversion (b); analog signal (c); analog after APD (d); intermediate frequency after BPF (e); original carrier frequency reconstructed after up conversion (f).

In the DRoF system the initial process is similar the RoF-IF as is shown in Fig. 3, however unlike RoF-IF and RoF-RF transmissions in which is performed in analod domain, the signal is digitized by ADC before optical transport. Considering the C-RAN architecture, this process is carried out in the BBU unit located in the CO. After the down-conversion technique, the intermediate frequency at 400 MHz is first normalized in order to establish an operation range on the ADC to prevent that the samples are recovered out of limit. The next step is the quantization, where the signal is discretized on a number of levels given by 2n (n is ADC bit-resolution). As a consequence, the signal has a new representation, being discrete in time and amplitude. The obtained samples are grouped in a serial sequence and then coded into a baseband digital data using a non-return to zero (NRZ). After that, the digitalized bit stream sequence is modulated by one MZM and sent over fiber. In the upstream direction, the generation and detection of the signal follows the same stages described for downstream

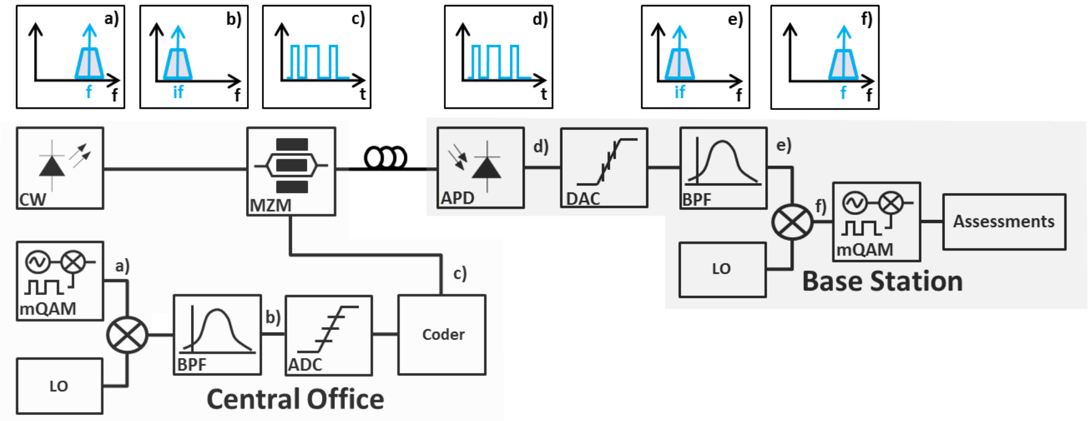

Fig. 3. DRoF schematic simulated where the letters illustrates: Original carrier frequency (a); intermediate frequency after down conversion (b); coded digital bit stream (c); digital bit stream after APD (d); intermediate frequency after DAC (e); original carrier frequency reconstructed after up conversion (f).

At the transmitter, during analog-to-digital conversion in the ADC, the system is affected by different sources of noise such as jitter and quantization. Jitter noise derives from the sampling clock jitter, while quantization noise is directly related with ADC resolution. However, quantization noise requires special attention because it causes a more severe impact on the system performance since it limits its dynamic range [19]. This noise is defined as the difference between the voltage of the input (yn) and output signal (yq). In an ideal ADC the error is uniformly distributed between - ½ LSB (least significant bit) and + ½ LSB, and the root mean square value of the error signal is given by (1), where Q is the bit resolution used on ADC [21].

$$\mathrm{RSM}_{\mathrm{eq(n)}} = \sqrt{2^{Q-1}\int_{-\frac{1}{2^Q}}^{\frac{1}{2^Q}} e_q^2(n)} = \frac{1}{\sqrt{3}2^Q} \qquad (1)$$

The signal-to-quantization noise (SNRQ) is given by the ratio of the root mean square value of the input signal and the root mean square value of the quantization noise. In the case of an uniformly distributed signal,$(\mathrm{RSM}_{x(n)} = 3^{-1/2})$, the SNRQ can be represented by (2).

$$\mathrm{SNR}_Q = 20\log_{10}\left(3^{-1/2}\,\sqrt{3}2^Q\right) = 6.0206Q \quad (\mathrm{dB}) \qquad (2)$$

However, as in proposed system the signal distribution is not uniform (M-ary QAM), then RSM of the error signal is calculated by the (3).

$$\mathrm{RSM}_{x(n)} = \left(\frac{\sqrt{M}+1}{3\sqrt{M}-3}\right)^{\frac{1}{2}} \qquad (3)$$

The corresponding SNRQ is obtained by the (4). It clearly shows that the increase of the bit

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resolution improve the signal-to-quantization noise.

$$\mathrm{SNR_Q} = 20\log_{10}\left(\left(\frac{\sqrt{\mathrm{M}}+1}{3\sqrt{\mathrm{M}}-3}\right)^{\frac{1}{2}}\sqrt{3}2^{\mathrm{Q}}\right) \tag{4}$$

$$= 6.02\mathrm{Q} + 10\log\left(\frac{\sqrt{\mathrm{M}}+1}{\sqrt{\mathrm{M}}-1}\right)\ \ (\mathrm{dB})$$

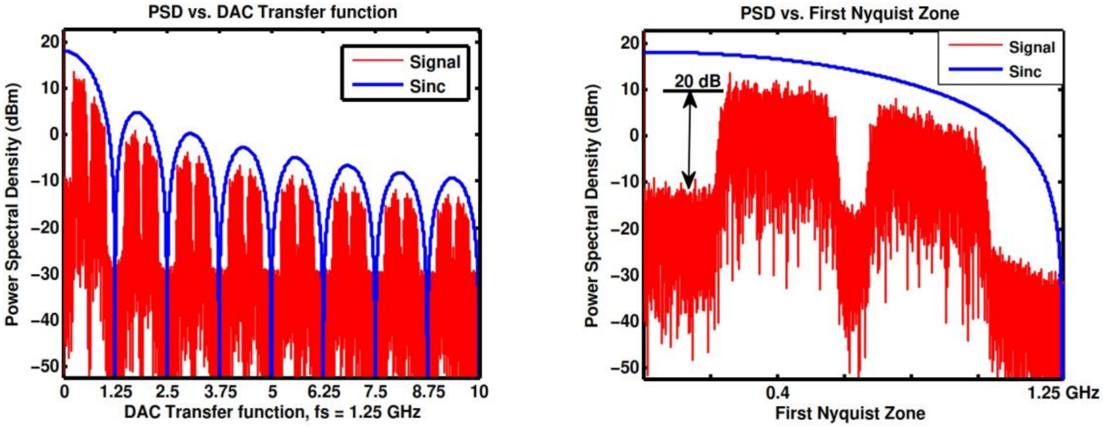
In the base station, at the RRH, the signal is detected by a photo-detector, transformed to the electrical domain and converted from serial to parallel. The main sources of degradation arise in the O-E conversion process through photo-detector noise and in the digital-to-analog process where DAC introduces jitter noise. In the overall system, there are other sources of noise introduced by modulators and lasers, however the letter are present in all optical systems and they do not outcome particularly from DRoF system, which is the focus of this work.

In the digital-to-analog process, the analog signal after DAC has spectral replicas of the original signal in the entire spectrum. According to (5), for a RF (f) spectrum, the equivalent spectrum R'(f) after sampled by a rectangular function, is given by the convolution of an impulse train and a pulse function unit [25], where d represents sampling rectangular pulse width proportional to the period, δ (dirac) is the Dirac delta function, and T represents the sampling interval which in the system is equivalent to DAC sampling rate, at 1.25 GHz.

$$\mathrm{R}'(\mathrm{f}) = \mathrm{R}(\mathrm{f}) \times \left(\mathrm{d}\sum_{\mathrm{n}=-\infty}^{+\infty}\left(\frac{\sin(\mathrm{n}\pi\mathrm{d})}{\mathrm{n}\pi\mathrm{d}}\right)\delta\left(\mathrm{f}-\frac{\mathrm{n}}{\mathrm{T}}\right)\right) \tag{5}$$

Fig. 4 (a) depicts the system transfer function according to (5). As it can be observed, the nulls of the sine cardinal occur in multiples of the ADC sampling frequency and the signal attenuation increases with frequency. On the other hand, the lowest Nyquist zone has higher spectral power as shown in a wider view in the Fig. 4 (b0. Based on these observations, in the last stage of the signal reconstruction, the 400 MHz replica is extracted using a baseband filter with 400 MHz and then up-converted to original frequency (5 GHz), by using a local oscillator (LO) at 4.6 GHz. The transmitted information is recovered and system's performance is measured using the Bit Error Rate (BER) and Error Vector Magnitude (EVM) metrics.

The down-conversion technique was used to relax the ADC sampling rate since it imposes severe impact in cost-effective the system and higher power consumption.



(a) (b)

Fig. 4. RF spectrum after DAC (a); Wide view of the extracted 400 MHz replica in the first Nyquist zone. (b)

B. Coexistence Scenario with Radio over Fiber systems.

In order to evaluate the implementation of a DRoF system in a coexistence scenario, a proposed scheme based on G.989.1 [8] specification is shown in Fig. 5. At the CO, legacy systems consist of G-PON (G.984.1) [8], XG-PON (G.987.1) [9] channels and the more recent standard comprised by 4 TWDM-PON channels. The ODN includes a coexisting interface (CEx) that ensures compatibility between the systems, fiber link and splitters which forward optical signals to the ONUs. The losses considered in the MUX, CEx and splitters were 2 dB, 1 dB and 21 dB, respectively. Finally the end users are interconnected through user node interfaces (UNIs). As there are no standards for radio over fiber technology, in this work it is proposed the use of digital (DRoF) and analog systems (RoF-RF and RoF-IF) at the same NG-PON2 OLT over PtP WDM since it can fulfil the bandwidth requirements on supporting high-speed transport (e.g. DRoF with CPRI line rate with up to 9.83 Gbit/s) and also meets the latency and delay requirements between the BBU and RRH

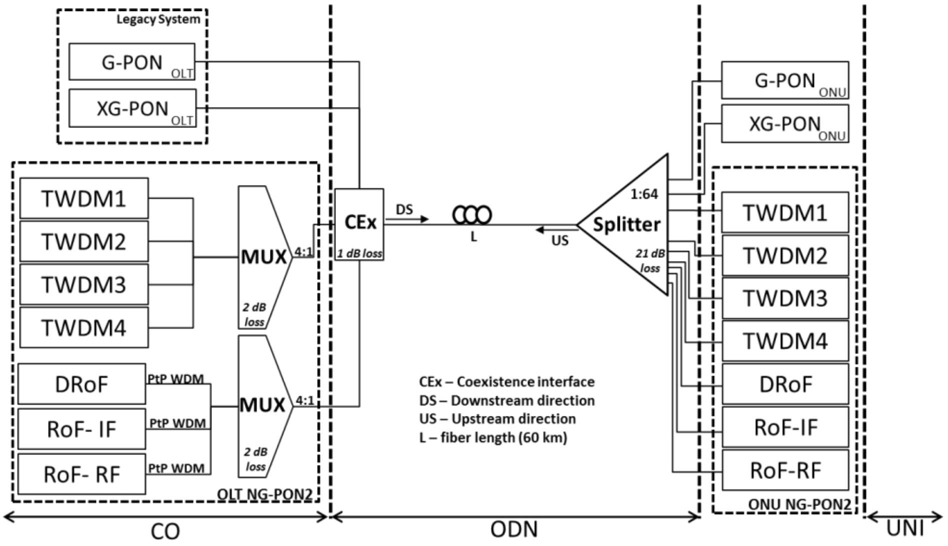


Fig. 5. Coexistence scenario with radio over fiber systems.

A topic of interest in coexisting scenarios refers to the wavelength to be used in new technologies [26]. An allocation plan used in our setup ensures the compatibility between legacy and new systems is represented in Fig. 5. As can be seen, the legacy systems have a reserved wavelength range for donwstream between 1290 nm - 1330 nm (G-PON) and 1260 nm - 1280 nm (XG-PON); and for upstream amid 1480nm - 1500 nm and 1575 - 1580 for G-PON and XG-PON, respectively. In G.989.1 specification the wavelength plan to be used is not defined, but it is recommended to use 4 to 8 TWDM channels. Ranges between 1530 - 1540 nm in the C band for upstream and 1595 - 1625 nm in the band L to downstream are also proposed. On the wavelength plan we propose use digital (DRoF) and analog signals (RoF-RF and RoF-IF) in L band within PtP WDM range, 1603-1625 nm for downstream and upstream.

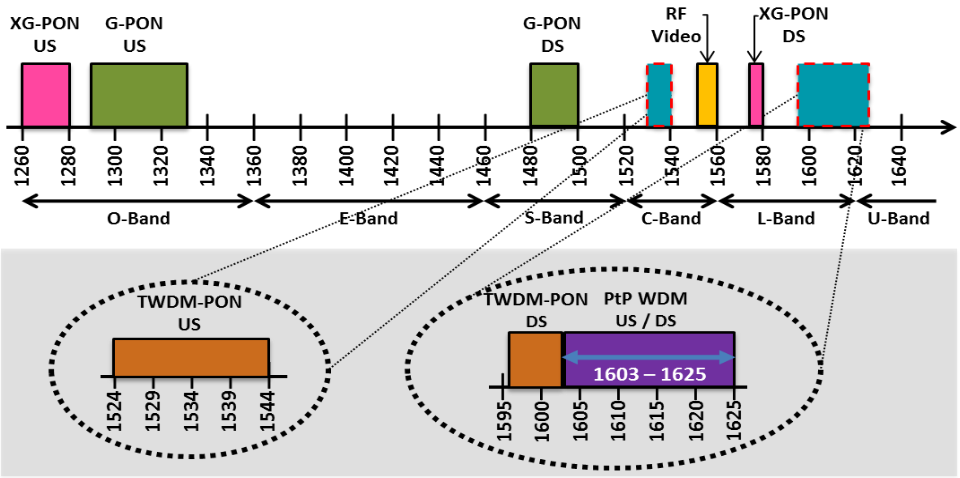


Fig. 6. Wavelenght plan for coexistence scenario.

IV. RESULTS

A. DRoF Analysis

In this section the results are discussed. The DRoF signal transmission in an isolated scenario is analysed. The transmission of a 16-QAM signal with bit rate 1.25 Gbit/s and optical source at 1600.8 nm emitted by a DFB laser is considered. In Table I the parameters used in DRoF, RoF-RF and RoF-IF transmissions are described.

TABLE I. Radio System Parameter

Parameter	Value
Carrier frequency	5 GHz
Modulation	16-QAM
RollOff	0.2
MZM extinction ratio	20 dB
Laser linewidth	10 MHz
APD responsitivity	0.7 A/W
APD noise	10 ^ -12pA/Hz ^1/2

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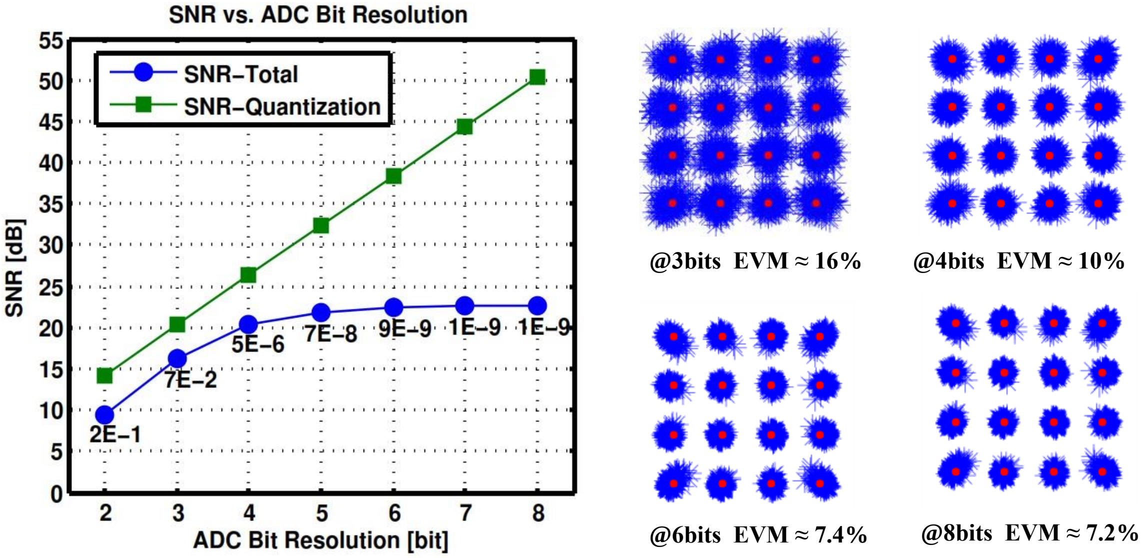
The ADC bit resolution is one of the most important parameters in DRoF system because it is related with main source of noise (quantization noise), and also the system's performance due to contribution to overall optical line rate. Therefore, we first highlighted the key impacts of the number of bits on the system in back-to-back transmission. To investigate how the quantization noise influences the performance, we calculated the SNR for different ADC bit resolution, as is shown in Fig. 7(a). The theoretical SNR quantization obtained from (4) demonstrates that when only this noise is considered, the transmission improvement is linear with a gain of approximamately 6 dB for each extra bit. However, considering other noises, such as jitter, the gain is more evident until 4 bits. After that, those become more predominant than the quantization noise and the SNR link converges in 6 bits with 23 dB (BER magnitude order of 1E-9).



(a) (b)

Fig. 7. Impact of the ADC bit resolution: on the SNR where markers highlight the BER value (a); On the 16-QAM constellation with correspondent EVM (b).

Fig. 7(b) depicts the impact of the bit resolution on the system's sensitivity as a function of the BER. These results emphasize the considerations of the previously presented analysis. The increase in the ADC resolution, from 2 to 6-bit, results in reduced quantization noise therefore improving greatly the BER. Beyond 6 bit the improvements are less significant and result in increased requirements in the components, therefore potentially increase in the cost. It is important to notice that to achieve an acceptable performance, e.g. below of the BER 1E-3, it is necessary to have at least 4-bit resolution. Also in Fig. 7(b) we can observe the impact of the bit resolution on the overall rate transmitted. As in the digitalization process, each sample is converted into a bit stream, the optical line rate will be given by the product of ADC sampling rate with the resolution (SR*Resolution). Considering the ADC sampling rate of 1.25 GHz, for 2, 4 and 8 bits of resolution, the optical line rate is 2.5 Gbit/s, 5 Gbit/s and 10 Gbit/s, respectively. As consequence, the sensitivity is more affected due to the errors caused by increase the optical line rate.

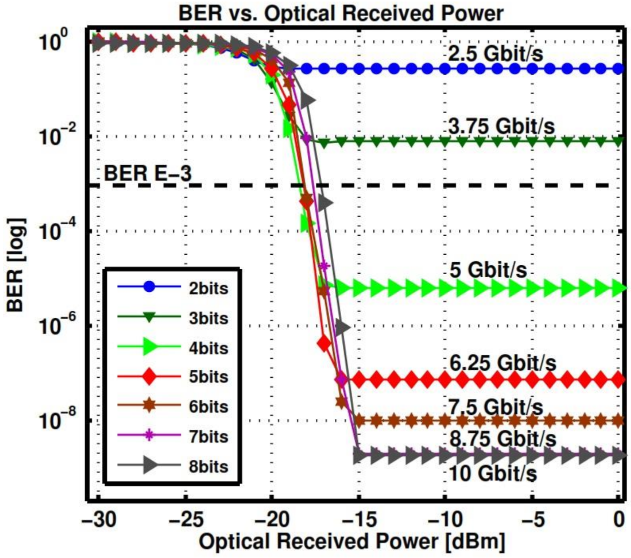


Fig. 8. System’s sensitivity where values inside of the plot represents the overall optical line rate.

The trade-off between the resolution and ADC sampling rate makes the implementation of DRoF systems a big challenge since higher data rates limit the link performance and increase the cost-effectiveness of the system. However, when the transmission requires a CPRI transmission for each sector of the antenna (e.g. MIMO) this challenge may become higher since the new overall optical line rate will be SR*Resolution multiplied by the number of sectors and also plus 10/8 factor derived from 8B/10B coder specified on the CPRI protocol. Therefore, this trade-off needs to be carefully studied, especially at the fronthaul segment where the use of legacy systems cannot offer the necessary bandwidth required by the transmission of digital radio signals.

B. Coexistence Analysis

In the following analysis, the performance of the DRoF system in a coexistence environment is evaluated. Based on previous analysis, a DRoF system with only 4-bit resolution with optical power of +6 dBm is used. In order to get a better comparison, transmissions of analog signals (RoF-IF and RoF-RF) were used. For all technologies, the following parameters are used:

- G-PON: 1310 nm (US) and 1490 nm (DS), 2.5 Gbit/s, NRZ, launched power +3 dBm;
- XG-PON: 1270 (US) 1577 nm (DS), 10 Gbit/s, NRZ, launched power +6 dBm;
- TWDM-PON: 4 channels 1596 - 1602 (DS) and 4 channels 1532 – 1535 (US), 10 Gbit/s, NRZ, launched power +6 dBm;
- RoF-IF - PtP WDM: 1605 nm (DS) and 1604 nm (US), lunched power +9 dBm;
- RoF-RF - PtP WDM: 1606 nm (DS) and 1603 (US), lunched power +9 dBm;
- DRoF - PtP WDM: 1607 nm (DS) and 1602 (US), lunched power +9 dBm;

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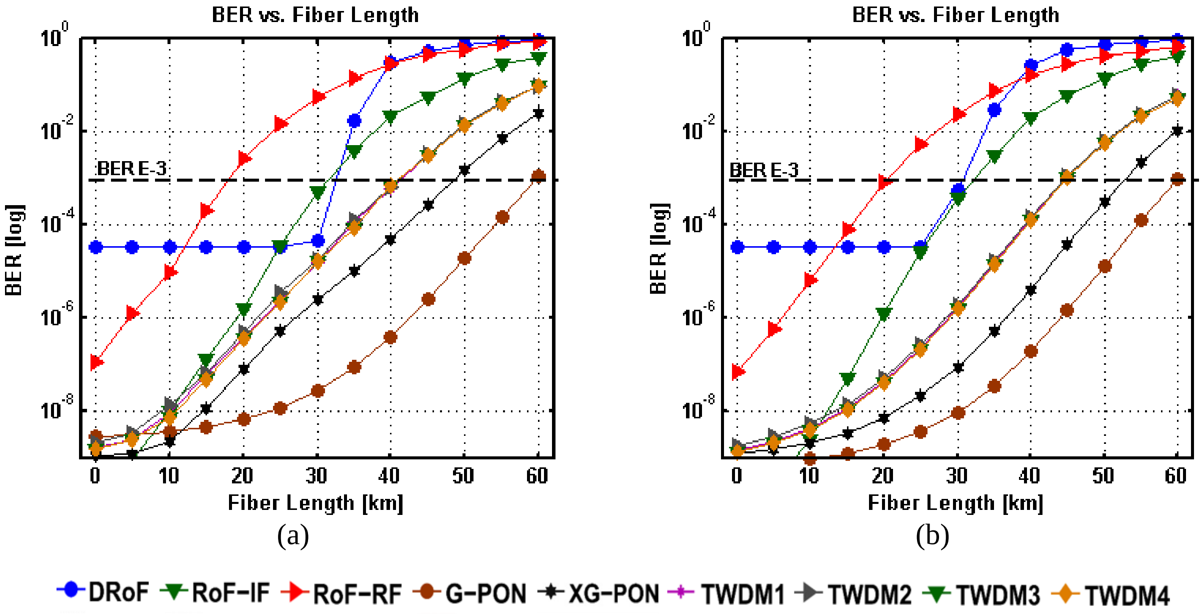
The simulations were performed in the downstream and upstream directions, with a SSMF ranging distance from 0 to 60 km. It were also considered 21 dB loss at attenuator located at the end of the fiber to simulate the power loss of a 1:64 splitter, 2 dB loss for each MUX and 1 dB in the CEx interface, as is described in the G 989.1 specification.

Fig. 9 (a) and (b) shows the system's performance of the coexistence proposed scenario, where it is possible to measure the BER as a function of fiber length. It can be noted that the performance for downstream and upstream directions are similar to DRoF, RoF-RF and RoF-IF and these transmissions are able to coexist with the other technologies, although they have different behavior. As described before, in analog transmissions the cumulative distortions from IMD, attenuation and dispersion are the main sources of penalties, which degrade the link dynamic range. It can be seen in downstream direction the down-conversion technique reduces these impacts, while the reach in acceptable limit (BER E-3) to RoF-RF is 15 km, for RoF-IF is 30 km. On the other hand, DRoF link do not suffers evident impact on the performance and the transmission remains constant from 0 to 25 km, even with 5 dB penalty of fiber attenuation.



(a)

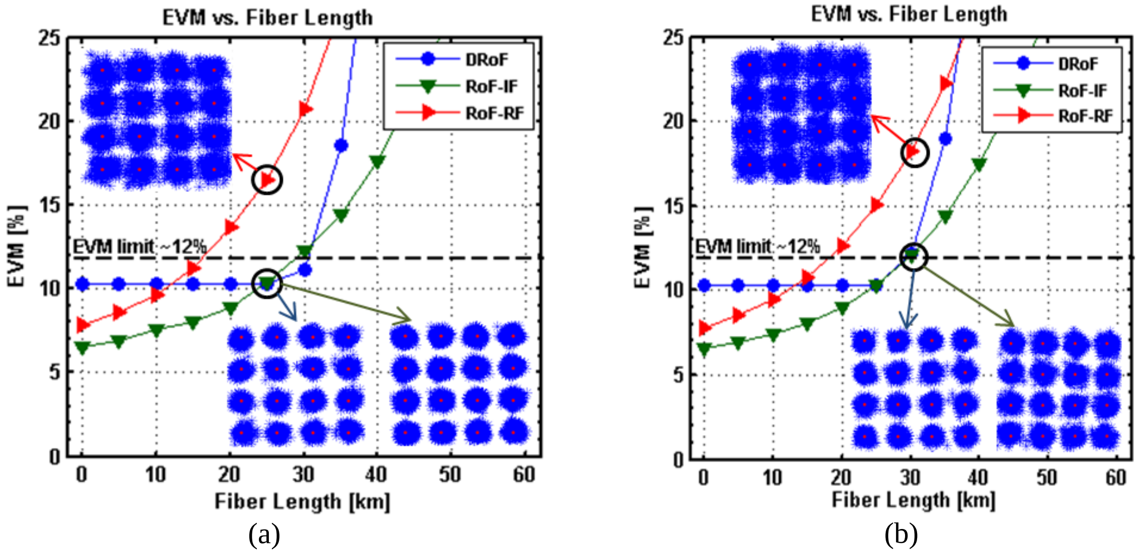
(b)

Fig.9. BER versus Fiber Length in the coexistence scenario: downstream direction (a); upstream direction

Unlike the DRoF system, which is quantization noise limited up to a given distance, the PON systems will have its behavior restricted by noise and distortion stemming mainly from dispersion. Fig. 9 (a) and (b) depicts that all PON generations reach up to 40 km showing that the power plan used is enough to overcome 12 dB loss due to fiber attenuation and more 21 dB loss used to simulate 1:64 spliter. The G-PON performs better than XG-PON and TWDM-PON in part because of its lower bitrate, for downstream and upstream the results are similar with BER close to 1E-3 in the maximum distance, 60 km.

The XG-PON and TWDM-PON have different performance even operating with similar configuration in terms of bit rate and power (10 Gbit/s and +6 dBm). It is possible to notice that for both directions the XG-PON performance is significantly better because of the different received power due to losses from MUX and CEx. While the XG-PON transmission suffers penalties of the CEx (1 dB), TWDM-PON channels accumulate losses introduced by MUX (2 dB) and CEX (1 dB) components, as illustrates Fig. 5. In the overall, the transmission suffers severe degradation with fiber length, deteriorating its performance due to, mainly, the chromatic dispersion, which becomes quite relevant in the performance of the system for this bit rate, limiting the reach of the TWDM-PON and XG-PON in 40 km and 45 km, respectively. However these distances meets the reach that the ITU-T G. 989.1 standard must support without mid-span reach extenders

Fig. 10 (a) and (b) illustrates EVM versus distance, an equivalent way to represent the performance of the radio transmissions. There isn't difference regarding to results discussed in the BER analysis, for both directions the performance is similar. The transmission of the RoF-IF and DRoF reach 30km inside of the 12% limit specified by 3GPP [27], while in the RoF-RF the signal degradation limits the reach at 15 km. The obtained diagrams inside the plot illustrate the constellation dispersion for all signals in 25 km and 30 km for downstream and upstream, respectively.



(a) (b)

Fig. 10. EVM versus Fiber Length for DRoF, RoF-IF and RoF-RF in the coexistence scenario: Downstream direction (a); Upstream direction (b)

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V. CONCLUSIONS

In this paper the main limitations and requirements regarding to the integration of optical and wireless networks in the new C-RAN architecture were investigated. In particular the implementation challenges that the digital radio over fiber (DRoF) system brings, nominally due to extra noise sources and potentially high optical line rate, were discussed. The trade-off between the ADC sampling rate and bit resolution causes severe restrictions on the transmission performance and raises the implementation costs. However, the results have shown that the low cost DRoF system proposed mitigates these limitations and have better performance than analog transmissions even with only 4-bit of ADC resolution.

In the coexistence context DRoF transmission remains within the limit established by the EVM and BER until 30km, confirming that radio interfaces, such as CPRI, can reach long distances with low cost of implementation. As the wavelength and power plan of DRoF systems are open, our proposal considers accommodation of the DRoF system at the NG-PON2 OLT within the range of wavelengths reserved for optional channels in PtP WDM-PON. On the other hand, the physical implementation of the DRoF system still reveals many challenges, but using the inherent advantages of the digital systems it is a promising solution that meets the changes in traditional network infrastructure and enables the construction of high-capacity networks for new broadband demands.

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