Cost-effective Digital Radio over Fiber System

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***Abstract*—Due to the increasing demand for high bandwidth applications for wireless networks, Radio–over-Fiber technology appears to be a great solution. The integration of optical fiber and wireless brings a lot of advantages and challenges to new mobile networks. To improve transmission analog Radio-over-Fiber links, a Digitalized Radio-over-Fiber scheme is analyzed on this work. Taking advantage of digital optical link, various impairments Through analyzing the BER and EVM, we compare the performance of the two technologies using the same fiber link.**

Keywords—Radio-over-Fiber; Digitized Radio-over-Fiber; EVM; BER;

I. Introduction

The constantly increasing demand for high-bandwidth services from subscribers has led to integration of optical network infrastructure and wireless broadband access. By combining the capacity of optical fiber with the mobility and ubiquity of wireless networks, a powerful system can be created to support the data traffic volumes.

In recent years, Radio over Fiber (RoF) is considered very promising technology for access networks because of several advantages [1], [2]: low fiber attenuation loss; The enormous bandwidth offered by optical fibers has high capacity for transmitting microwave signals; Optical fibers consist of dielectric materials and do not conduct electricity, therefore the fiber is immune from Electromagnetic Interference (EMI); furthermore, it is independent of modulation format and protocol and useful for future flexible access networks.

The fundamental principle of RoF transmission is the transport of information over optical fiber by modulating the light with the radio signal. RoF technology uses a linear optical fiber links to distribute Radio Frequency (RF) from a Central Station (CS) to Remote Antenna Units (RAUs) or Base Station (BS). This relies on simplifying the RAUs, since they only need to contain optoelectronic conversion devices and amplifiers. Consequently, power consumption, equipment cost and maintenance costs are reduced [4].

Some approaches using Analogue RoF and Digitized RoF have been proposed in several systems [5]–[7]. In [5], a Digitized RoF scheme based on bandpass sampling is introduced and a comparison with analogue system is presented, using Bit Error Rate (BER) and Signal to Noise Ratio (SNR) results. Digital RoF shows better performance over Analog link. Otherwise, several digital signal processing techniques are implemented and used to demonstrate the high capacity of RoF and wireless data transmission [6]. Most recently, [7] exposes an overview of digitized RoF technique and proposes an analysis of energy consumption in optical transport. Results show the digitized RoF technique is most energy efficient for larger cell size.

Analogue RoF suffers from Intermodulation Distortions (IMD), and the dynamic range of analogue links decreases linearly with the increasing length of the optical fiber. Otherwise, an digitized RoF transmission can maintain its dynamic range independent of the fiber transmission distance. As a result, the DRoF can be based on low-cost digital hardware with a high dynamic range capable of supporting long distances [5].

The main goal of this paper is to propose a DRoF scheme as an alternative to analogue RoF, aiming both cost and energy efficiency. A comparison between digital and analogue RoF links is made in terms of Error Vector Magnitude (EVM) and BER. Moreover, the proposed DRoF system has good performance using low ADC resolution, which reduces costs and moderates hardware requirement.

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II. RoF Technologies

A. Analogue RoF

On this RoF technology, the analog signal transmitted over the optical fiber can either be radio frequency (RF) signal, intermediate frequency (IF) signal or baseband (BB) signal. In the optical transmitter, the RF/IF/BB signal is modulated onto the optical carrier by either using direct or external modulation of the laser. The signal distribution through RoF has the advantage of simplified BS design, as mentioned previously, however it is susceptible to fiber chromatic dispersion and other impairments from analog communication systems. Despite the impairments inherent to analog communication systems, the Analog RoF systems has a lot of benefits and advantages such as:

Large bandwidth: the optical fiber technology offers a huge bandwidth. The integration of optical fiber from central office to the RAUs raise the capacity to transport information transmitting microwave signals. The high optical bandwidth enables high speed signal processing which is more difficult, and sometimes even impossible, to do in electronic systems.

Immunity to Radio Frequency Interference: Immunity to Electromagnetic Interference (EMI) is a well-known and very attractive property of optical fibers communications. This property, together with the fiber's low attenuation (around 0.2 dB / km), are a good choice for signal transmission in radio frequency.

Easy Installation and Maintenace: In RoF systems, complex and expensive equipment is kept in the central office, thereby making the RAUs simpler. That's one of the major advantages of RoF Technology because reduce the base station complexity implies on smaller and lighter RAUs, effectively reducing system installation and maintenance costs.

Muliple service operation: In RoF systems, subcarrier multiplexing (SCM) and wavelength division multiplexing (WDM) can be used to distribute multiple radio signals over one single optical fiber. This leads to a network flexibility for integration with others access networks (e.g. Passive Optical Networks).

B. Digitized RoF

While analog RoF link suffers from some impairments such as mentioned previously, the Digitalized RoF appears as an alternative to next generation RoF systems. The digitalization of an RF signal consists in produce a sampled digital signal in a serial form that can be directly modulated on an optical carrier. Modulation of the digital signal onto an optical carrier minimizes the nonlinear effects originating from the optical-to-electrical conversion function presented on analog RoF. In order to use not so high sample rates at the ADC/DAC components generally the bandpass sampling technique is applied to the RF signal. All the functions and protocols still be centralized at the central office and the digital signal can be recovered by direct detection at the RAUs. The DRoF inherent benefits from analog RoF and It can maintain its dynamic range independent of the fiber transmission distance until the received signal goes below the sensitivity of the link. Other improvement presented on DRoF systems is that it utilizes less transmission power to archive the same performance of analog RoF.

III. RoF and DRoF Links Design on VPI

A. RoF Link Design

The VPItransmissionMaker [8] simulator is used to implement RoF and DRoF systems. Figure 1 shows a macro view of the implemented RoF schematic and, in the Figure 2,signal propriety in each stage of the system is presented.

In downlink path, from central office (CO) to base station, a bit sequence is generated by Pseudo Random Binary Sequence (PRBS) and modulated as M-QAM. Then, the signal is modulated externally with MZM and a distributed feedback (DFB) laser is used as optical source to transmit the generated signal over a standard single mode fiber (SSMF).

In the base station (BS) the optical signal is detected using a positive-negative (PIN) photodetector and converted to electrical domain. This signal is then down converted to the appropriate carrier frequency and again filtered using a SSRC to recover the data. The system performance is assessed through both Bit Error Rate (BER) and Error Vector Magnitude (EVM) quantification, which are provided by VPItransmissionMaker assessment tool. In the Figure 2 we see the signal propriety in each stage of the system.

B. DRoF link design

Figure 3 shows the macro view of the DRoF system and, in the Figure 4,signal propriety in each stage of the system is presented. The main difference compared to RoF system is only ADC and DAC components.

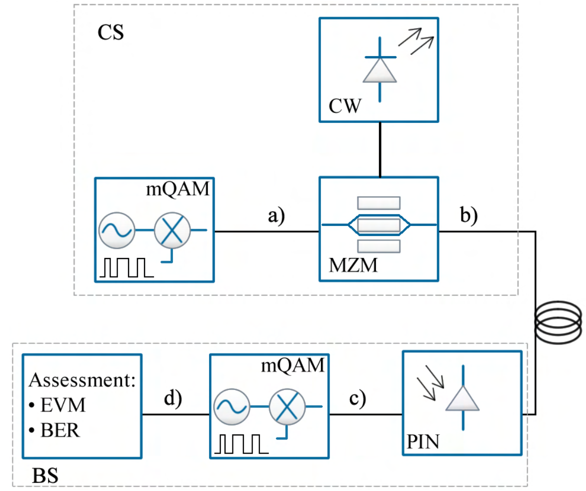

Fig. 1. RoF schematic.

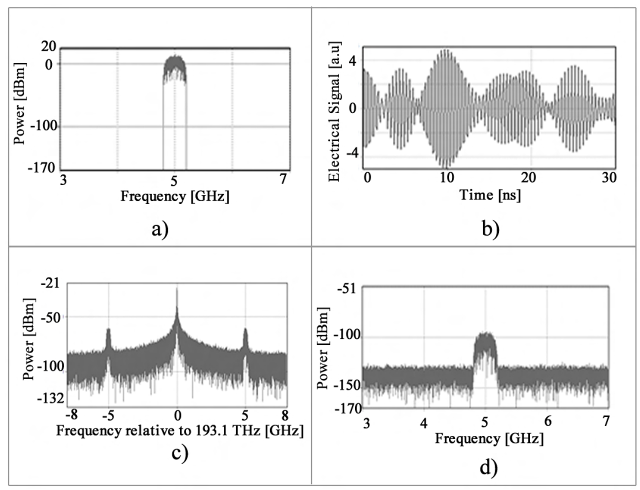

Fig. 2. Signal propriety of RoF system. a) Carrier frequency, b) Analog signal, c) Spectrum optical, d) Carrier frequency

These hardware components were simulated using a set of blocks from VPItransmissionMaker and all of the processes of conversion digital-to-analog and/or analog-to-digital were implemented respecting realistic requirements. All process is performed through the following steps: sampling, normalization, quantization and codification.

In sampling step, the sampling rate to digitize the analog signal is selected applying Nyquist criterion wherein the frequency sample must be at least twice the signal bandwidth of the highest bandwidth [10]. After that, the signal is normalized to ADC dynamic range to prevent that signal samples are recovered out of limit.

In the quantization process, the continuous signal is discretized according to levels defined by ADC resolution ($2^{resolution}$). At the end of this process, the signal has a new representation discrete on the time and amplitude domain. The signal is converted to binary sequence and then encoded

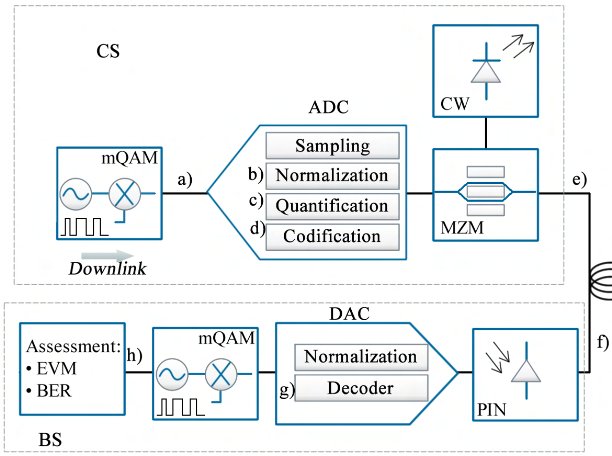

Fig. 3. DRoF schematic.

using a Non Return to Zero (NRZ) coder. After that, the bit stream is modulated using MZM. Each sample is converted to into a bit stream sequence according ADC resolution. Therefore, the overall data rate on optical link is the product of bit rate and resolution (data rate * resolution). Higher data rate impose limit on performance link and increases system costs. The trade-off between optical link vs ADC resolution has a significant challenge related to practical DRoF implementations and should be carefully considered since the cost effective may be expensive compared to RoF systems.

In the Base Station, the digital bit stream is detected using a PIN and processed to get the parallel digital data. The DAC is employed to convert this parallel bit stream to an analog signal. This process is shown in the points f and g of the Figure 4 and it is performed through normalization and decoder. Similar to the process in ADC, the signal is first normalized for dynamic range to avoid that samples be recovered out of the limit. Finally, in the last stage the samples are grouped in parallel bit sequence. In the frequency domain, this analog signal has spectral replicas of the original carrier frequency in every Nyquist region, the signal would be recovered by demodulating corresponding replica.

IV. Results

To compare RoF and DRoF systems, it was considered a scenario with 2.5 Gbit/s, 16-QAM modulation using an optical source 1550 nm emitted by DFB laser with power -12 dBm. In order to make a fair comparison, both systems use the same parameters summarized on Table I, with the exception of 3 to 8 bits in the ADC resolution.

Figure 5 shows the EVM versus ADC resolution. Results present the efficiency of the ADC implemented. As expected the system performance increases as more bits resolution are used. For all scenarios, the EVM remains in 5%, below of the limit considered for some technologies wireless, such as LTE [11]. However as described, the ADC resolution contributes to overall data rate on fiber and consequently costs of the system. In our implementation is possible to observe that from 6 to 8

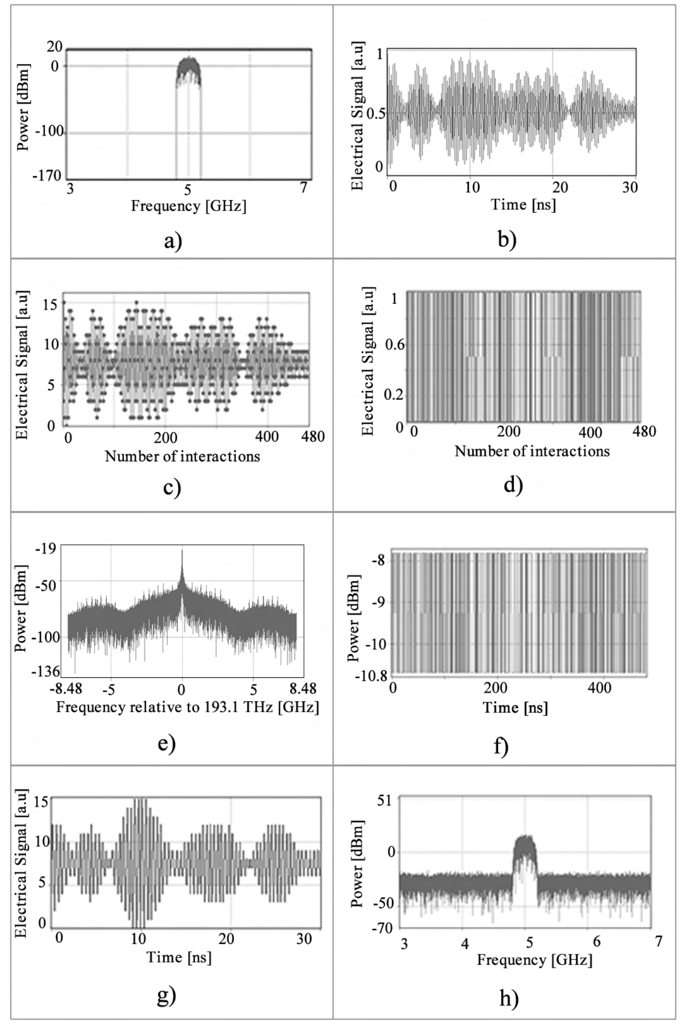

Fig. 4. Signal propriety of DRoF system. a) carrier frequency, b) normalized signal, c) quantized signal, d) coder signal, e) optical spectrum, f) signal over fiber, g) decoder signal, h) carrier frequency.

TABLE I. System Parameters.

Parameter	Value
Carrier Frequency	5 GHz
Modulation	16-QAM
MZM Extiction Ratio	20 dB
Laser linewidth	1MHz
Attenuation coefficient	0.2 dB/km
Dispersion parameter	17 ps/nm*km
PIN responsitivity	1.0
PIN noise	$10.0^{-12} pA/Hz^{1/2}$

bits the system has no performance gain. On the other hand, the received constellation diagram demonstrates small penalty in transmission between 3 to 6 bits resolution. This ensures that is possible to use ADC with low resolution.

The systems RoF and DRoF were compared in the transmission considering various distances, from x to y km, with ADC resolution fixed on 3 bits. To that extent, EVM

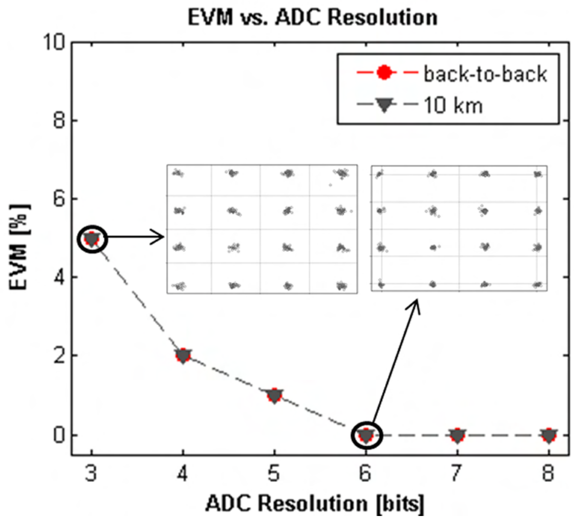

Fig. 5. EVM versus ADC resolution.

versus Fiber Length is plotted in Figure 6. One notes, for instance, that EVM in the digital system remains constant until 30 km, and only in 40 km and 50 km the systems suffer a small penalty, but the transmission remain inside of the limit. On the other hand, in the analog system the transmission has better performance than digital only for short distance. However, the signal suffer visible penalty when the distance is increasing. As is displayed, for 30 km the EVM is over 12% desired limit error. This ensures that digital transmission can operate for long distance having low sensibility for RoF and DRoF, which are -18 to -22 dBm respectively.

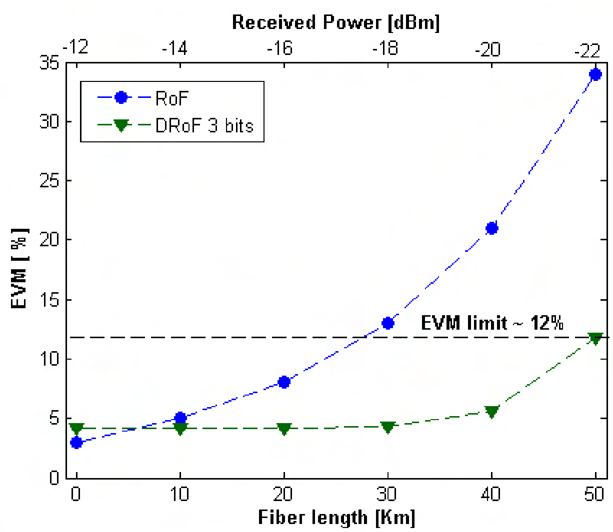

Fig. 6. EVM versus Fiber Length.

The two systems also were measured through of the BER. Similar to previous analyses, the analog transmission has a better performance than DRoF in short distances, up to 10 km that corresponte -18 dBm of the power received. In this point, for instance, the BER is 1^{-11}. However the performance of the RoF system start to decrease with fiber distance, so that after 30 km the BER is 1^{-3}. On the other hand, in digital transmission the BER is constant until 30 km, even with total bit rate on fiber being three times more than RoF system. The diagram constellation plotted in the BER limit ensure the better performance of the DRoF system, as shown in Figure 7.

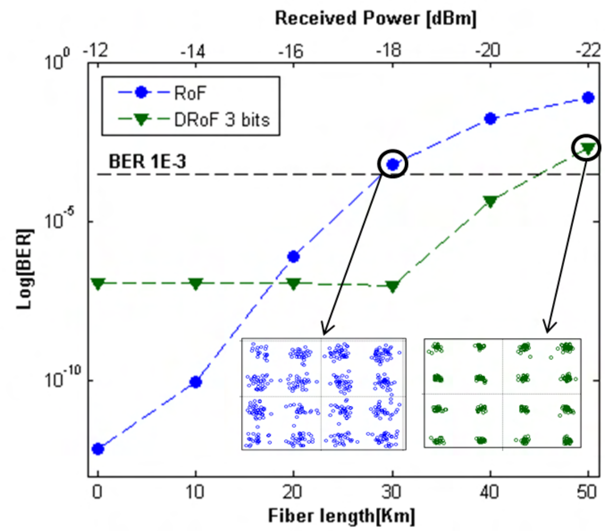

Fig. 7. DRoF schematic.

V. Conclusion

In this paper we presented a discussion related to the main characteristic of radio over fiber systems. Moreover, we proposed a new digital radio over fiber design, which allows both decreasing of the cost ADC deployed and transmission of a higher data rate link over long distance, i.e., 2.5 Gbit/s, up to 50 km.

Comparing the systems, the results highlight an evident advantage of using digital transmission with respect to analog signal in terms of: higher date rate, long transmission distance and cost-effective. Take advantage of the mature digital systems, our proposal shows that DRoF transmission is a better solution for new broadband requirements.

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