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Performance Evaluation of a real time OFDM Radio Over Fiber System at 2.5 GHz using Software Defined Radio SDR

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***Abstract*—This paper presents the implementation of an OFDM radio over fiber (RoF) system at 2.5 GHz using software defined radio (SDR). In this work, first we present an introduction of the main concepts about radio over fiber and an orthogonal frequency-division multiplexing (OFDM) system at 2.5 GHz, then we present a comparison of an OFDM RoF system in three scenarios, modifying the wireless distances and the optical fiber distance in order to evaluate the performance of the system taking into account the symbol error rate (SER) vs signal to noise ratio (SNR) curves.**

***Index Terms*—Radio over Fiber, RoF, LTE, OFDM, SDR, Real-time System**

I. INTRODUCTION

In the last few years the mobile data traffic growth, the increase in the number of users connected to the networks and the new services development have required a progressive updating of the standards and technologies managed by the mobile operators. Long Term Evolution (LTE) is the standard for 4G mobile networks communications, in which two multi-carrier multiplexing schemes coexist in the physical layer: Orthogonal Frequency-Division Multiplexing (OFDM) in the downlink and Single-Carrier Frequency-Division Multiple Access (SC-FDMA) in the uplink [1].

The aim of this paper is to study OFDM since the downlink has the highest requirements by the end user. OFDM is an orthogonal frequency division multiplexing whose purpose is to multiplex a data stream over time by assigning it a portion of the available bandwidth in the spectrum. The mechanism consists of a set of orthogonal sub-carriers that are a multiple of an original carrier, each one carrying a lower-rate stream encoded on digital modulation formats. This scheme is characterized by some advantages in comparison to traditional modulations used in previous standards of mobile telephony, as it has greater transmission rate, it is more spectrally efficient and it also has lower bit error rate [2].

On the other hand a RoF system is also known as a fiber system wireless (FI-WI) [3]. In a RoF system the objective is to carry the information through the optical fiber by modulating the light signal with a radio signal [4]. RoF is widely used to provide access in wireless communications with a wide range of applications and coverage for locations where wired media are not suitable [5].

Basically a RoF system is composed of a Central Station (CS) or Header and a Base Station (BS). The RoF system processes the RF signal at the CS and uses fiber optics to distribute the RF signal to the BSs [6] [7]. The CS is the gateway between the transport network and the BSs, the BS handles the communication with the users. This is specially important when designing networks based on the C-RAN architecture which states the use of optical fiber as the fronthaul physical layer [8].

The new mobile network generation requires new features for its physical layer. Radio over Fiber links provides an advantage since it will be possible to send higher data rates through these systems for applications that require it [9]. Moreover, the evaluation of the OFDM multiplexing at 2.5 GHz for different scenarios allows to know how it is the real time behavior of this technique in a future LTE link implementation operating at 2.5GHz.

In this paper we first show the SDR interface of the OFDM system built in GNU Radio, then we describe the physical setup of a transmitter and receiver system with a radio-fiber link. In the experiment we modified the wireless distance and the fiber optical distance in order to assess the performance of the OFDM RoF system. Finally we describe the conclusions of the obtained results.

II. GNU RADIO INTERFACE

This section describes the software defined radio (SDR) implementation of the OFDM transceiver along with the design parameters used for transmission.

First of all GNU Radio is a SDR framework, for designing digital signal processing (DSP) radio systems on a software basis. Its structure consists of a python-based graphical user interface with connected processing blocks that perform operations on the signals and create the so called flowgraph.

GNU Radio provides blocks for OFDM signal modulation and demodulation, which can be used openly for experimental purposes. An example for WiFi generation is also provided in the GNU repository. Whereas 802.11p (WiFi) is a well studied scheme for OFDM communications [10], the purpose of this paper is to evaluate an OFDM system using LTE parameters. Main differences of the LTE standard are the sample rate, bandwidth, and number of used subcarriers. .

A. *OFDM Parameters*

As already mentioned, the LTE standard sets a number of sample rates and fast Fourier transform (FFT) size for each bandwidth [11]. In this work we chose a 128 FFT for the design which allows up to 128 information sub-carriers. The number of sub-carriers used has direct influence over the efficiency of the system, as a large number of sub-carriers could increase the peak-to-average power ratio (PAPR). In this experiment we used more sub-carriers than the recommended in order to observe this effect. The recommended number of subcarriers for the downlink is 76 [1].

We chose quadrature phase shift keying (QPSK) as a digital modulation which consists of two bits transmitted per symbol for data coding and binary phase shift keying (BPSK) for header information. On the other hand, the LTE extended guard interval has to be as 25% of the size of the FFT, so we chose a length of 32 of the cyclic prefix [12]. Table I below shows the main OFDM parameters that have been covered.

Table I: OFDM Flowgraph Parameters[10]

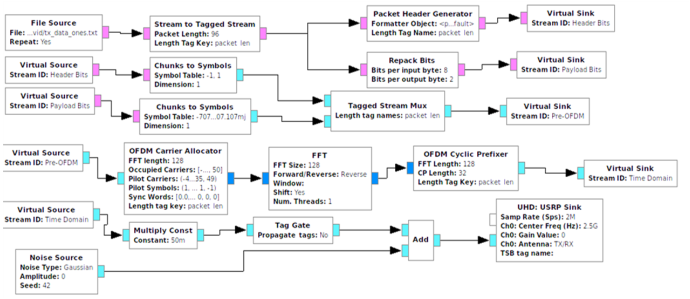
Parameter	Symbol	Value
FFT size	N	128
Modulation Technique		QPSK/BPSK
Bits per symbol	M	2/1
Cyclic Prefix	CP	32
Sample rate	samp_rate	1.92 Msps
Number of used carriers	Nu	90
Number of pilots	Np	10

LTE also specifies a sample rate for a given FFT size, therefore for 128 FFT bins the system should use 1.92 Msps. As one of the main objectives of this paper is to measure performance of the multiplexing scheme, the transmission focused only on packets avoiding the error checking of a CRC32.

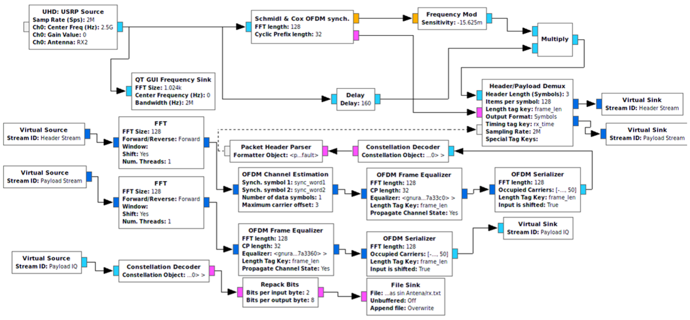
Finally, 10 sub-carriers were used for channel estimation and a Schmidl-Cox method with two 128-length training sequences was used from the OFDM digital blocks.

B. *OFDM Transmission and reception*

The OFDM transceiver architecture was generated in GNU Radio as a chain of interconnected blocks as shown in figure 1. First, data was taken from a text file source and converted into a tagged stream within the flowgraph. Then this input stream enters a block to generate a packet header while the payload information is repacked into two bits for conversion to digital symbols. The header data is encoded in BPSK and the payload in QPSK. The stream is then passed to the OFDM modulator blocks consisting of the OFDM Allocator (serial to parallel aligning), an inverse FFT block and the cyclic prefix insertion block. The amplitude of the time signal was attenuated to avoid problems with the digital analog converter (DAC) and a digital noise Gaussian source is added to the signal at this point. Afterwards, the amplitude of the resulting signal is controlled and the samples are delivered to the Universal software radio peripheral (USRP) sink block. The signal samples are sent to the hardware and it carries out the DAC and upconverting process.



(a) Transmitter side



(b) Receiver side

Fig. 1: OFDM GNU Radio flowgraphs

On the receiver side, a Schmidl and Cox synchronization is carried out first to detect the beginning of the frame. Then the signal passes through a demultiplexer block that separates the payload from the header and features a loopback to ensure that the packets arrived correctly. The header and payload signals are demodulated with a forward FFT block, a channel estimation block (just for header only), frame equalizer blocks and a digital symbol serializer. Finally the digital symbols are decoded and repacked into bits and then the stream finally enters the file sink.

C. *Random noise source*

In order to have control over the signal to noise ratio (SNR) a noise source was added to the flowgraph. The Gaussian noise source amplitude is determined by equation 1.

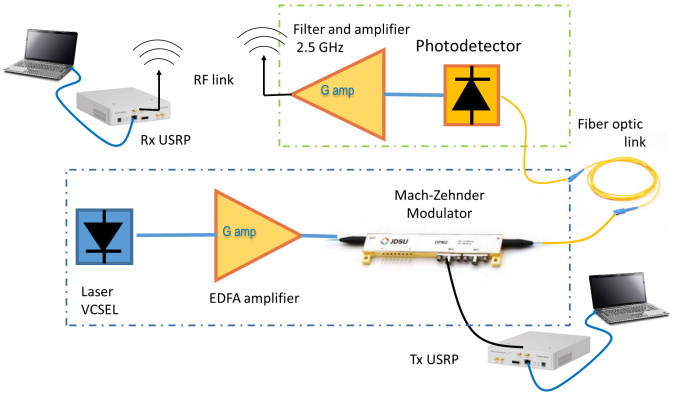


Fig. 2: Experimental OFDM RoF link setup

$$A_n = \frac{1}{\sqrt{10^{0.1*SNR}}} \tag{1}$$

Some experiments were carried out to determine the maximum level that still allowed a successful transmission by varying the level of the noise amplitude. Amplitude levels from 0.00 to 0.16 with steps of 0.02 were then introduced for the noise signal amplitude which led to different levels of actual SNR depending on the configuration of the setup used.

III. EXPERIMENTAL SETUP

This section details the hardware and software features that enable the implementation of a real time OFDM RoF link. The methodology for carrying out the measurements is also presented.

A. *Design*

The system design was divided into three segments as shown in figure 2. The generation of an OFDM signal and its analysis at the end of the receiver using SDR and Universal Software Radio Peripheral (USRP) are the first segment. The transmitter is the second segment and it includes the elements that allow transporting the OFDM signal through a fiber optic link at a predetermined frequency. In the last segment, the optical OFDM signal is sent through an RF link.

For the optical link implementation, a VCSEL (Vertical-Cavity Surface-Emitting Laser) laser was used. A Raycan pigtailed VCSEL was driven by a Thorlabs ITC8052 Laser Diode Current Control Module and a TCLDM9 Temperature Controlled Mount. The Amonics Optical Amplifier AEDFA-IL-18-BFA and two USRP N210 were used. The Photline (MXAN-LN-20) Mach-Zehnder modulator (MZM) allowed optically modulating the OFDM signal generated by the Tx USRP. The optical link included single mode optical fiber of 500 m. At the end of link a New Focus High Speed Photodetector 1414 was used to convert the signal to the electrical domain. The received electrical signal was amplified by the amplifier ZX60-2534M (MiniCircuits) and transmitted by a broadband double ridged Horn antennas A-INFO LB-880-NF. Finally the RF signal at 2.5 GHz was received by another Horn antenna and processed by the Rx USRP. The computers processors linked to the USRP were: Intel®corei5^{TM}and corei3^{TM}.

The design of the transmitter and receiver was implemented in GNU Radio. Two computers are used in order to create the transmitter and receiver.

The hardware-software interface was performed in two steps. First, the USRP Sink and Source block were initialized, in this way the program identifies where to send or to receive the digital samples. On the other hand, the connection between the USRP and the computer is achieved through a 1GB Ethernet cable, which sends the digital samples directly to the built-in USRP's FPGA and then it performs up-conversion at the specified RF frequency according to the daughterboard capacities.

B. *SNR and SER measurement methodology*

The methodology used for the experiments involved carrying out measurements of the two variables related to the figure of merit chosen (SER and SNR). To obtain the data, three scenarios were proposed usign a 500 m optical link and the RF link using a short coaxial cable or horn antennas at different distances (1.45 m and 8 m). The table II summarizes the setups and its features.

Table II: Setup configurations

Scenario	**Optical link**	**RF element**
Setup 1	Short link	Coaxial cable
Setup 2	500 m	Horn antennas at 1.45m
Setup 3	500 m	Horn antennas at 8m

For the actual on-field measurement of the SNR, a spectrum analyzer with RBW of 30 kHz and a window of 2 MHz was used. First, we conducted signal power measurements by setting on only the gaussian noise source for each one of the levels. Then, other measurements were made to determine the signal power of the OFDM signal with the noise on. The computation of the real SNR was performed by obtaining first the average power of the spectrum analyzer FFT bins according to equation 2.

$$P_{avg} = \frac{1}{B} \sum P_i \Delta f \tag{2}$$

Hereafter, equation 3 was used to find the signal-to-noise ratio taking into account that the noise is also present in the transmitted signal this is the reason for subtracting it while computing the ratio.

$$SNR = 10 \log \frac{P_s - P_n}{P_n} \tag{3}$$

The SNR measurements were performed in a systematic way. In particular, for the collection of SER data at the receiver, a series of SNR measurements were made based on the amplitude of the digital noise, taking steps of 0.02 units of amplitude of the noise in a span from 0.00 to 0.16..

For the SER measurement, a text file with a known sequence and fixed size was transmitted repeatedly for 30 seconds. An offline analysis was performed on the receiver in order to compare each symbol of the sent and received file. To carry out this analysis it should be considered that each character sent using a constellation of QPSK digital symbols represents four transmitted digital symbols.

The offline analysis consists of a C++ script that aims to check the number of symbols received (four times the original file) and decompose each symbol to verify the parity every two bits, i.e. each QPSK symbol. The experimental SER is determined from the expression 4.

$$SER = \frac{Number\_of\_errors}{Total\_symbols\_sent} \tag{4}$$

Finally, this measurement was made for each noise level established in the transmitter, and for each configuration system (optical fiber and RF link) in real time. In this way, the experimental SER vs. SNR curves were obtained.

IV. EXPERIMENTAL RESULTS

For the three scenarios the SER vs SNR curves were obtained. These are illustrated in figure 3. As can be observed, the behavior of the error rate tends to decrease with increasing SNR as expected. However, only rates of up to 10^{-2} are achieved in the sceneries using antennas and just a minimum 10^{-3} rate using a direct connection with coaxial cable. In order to be able to observe lower error rates, the transmission time should also be increased, but this is limited by the size of the file that can be received.

The results also reflect the decrease of the SNR and its span due to losses by slow and fast fading, going from values of around 40 dB for the first setup, maximum 23 dB for the second setup and a maximum of 12 dB for setup number three. The latter occurs as a consequence of the path losses due to the distance of the antennas which happens to be a major design parameter to target a desired performance.

During the experiments the importance of controlling the digital signal amplitude to avoid nonlinear distortions in the PA of the USRP was observed. Very high amplitudes imply an increment of the errors in the receiver. On the other hand, the gain of the USRPs should also be fixed. Increases in SER were observed when the gain in the receptor was increased. This converges in a relationship between the distance of the antennas and the actual gain of the transmitter and receiver. In other words the performance is affected by the maximum SNR value obtained for a maximum fixed gain value according to the distance.

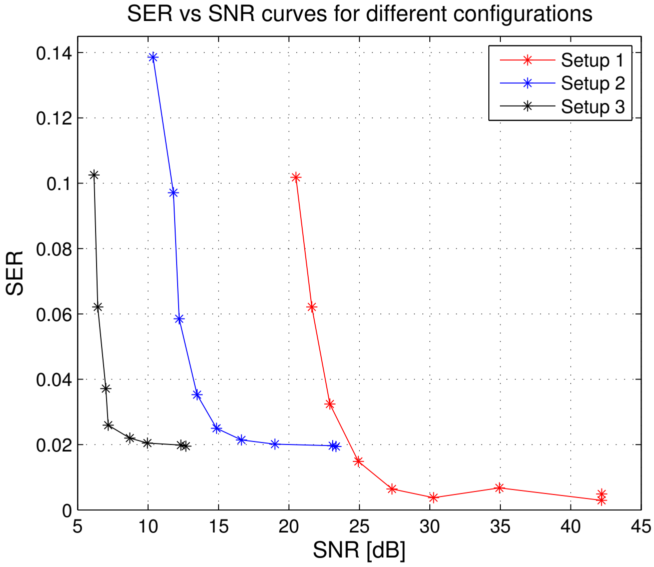


Fig. 3: SER vs SNR curves for each setup configuration

Finally, observations performed by varying the optical length demonstrated non significant effects over the performance due to the use of short distances. In further works, other distortions caused by dispersion over the optical link should also be addressed.

V. CONCLUSION

An OFDM system was implemented using RoF using a frequency of 2.5 GHz. An SDR interface using GNU Radio was implemented and tuned for parameters close to LTE. Three mounting configurations were made using, for example, a coaxial cable or horn antennas for the RF link and a 500m fiber optic link. A methodology was designed for the measurement of SER and SNR. The SER vs. SNR curves were obtained showing the performance of this system for the different configurations. An acceptable performance of the system was only present for the highest values of SNR in each configuration setup.

It was observed that the flowgraph parameters in terms of amplitude of the signals are key to the performance in terms of error. Evaluation of the influence of the parameters of other elements such as the polarization point of the optoelectronic modulator are proposed for the following works.

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