Analyses of Dual Polarization WDM and SCM Radio over Fiber and Radio over FSO for C-RAN Architecture

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ABSTRACT

In this paper, the transmission schemes for Centralized Radio Access Network Architecture (C-RAN) based on combination of two technologies - Radio over Fiber (RoF) and Radio over FSO (RoFSO) are simulated and experimentally verified. The proposed setups are optimized for Long Term Evolution (LTE) with 20 MHz bandwidth using 64 Quadrature amplitude modulation in terms of Error Vector Magnitude (EVM). At the first, the measurements of Polarization Division Multiplexing using combination of RoF a RoFSO (PDM-RoF/FSO) is compared with simulation models. This is further extended by combination of PDM-Wavelength Division Multiplexing (WDM)-RoF/FSO and PDM-Subcarrier Multiplexing (SCM)-RoF/FSO, respectively. Results indicate better performance of PDM-SCM-RoF/FSO than WDM RoF/RoFSO in terms of launch power to reach EVM limit.

Keywords: *Radio over Fiber; Free space optics; Dual polarization; Wavelength division multiplex, Long term evolution; Cloud radio access networks*

1. INTRODUCTION

Due to the rapid deployment of mobile market and new incoming technologies it is necessary to satisfy global mobile data traffic requirements, which reached 3.7 PB per month at the end of 2015, what is i.e. growth of about 74 % compared to year 2014 [1]. To accomplish these traffic demands several wireless technologies have been introduced, for instance Worldwide Interoperability for Microwave Access (WIMAX), Long Term Evolution (LTE), Wireless Fidelity (Wi-Fi) etc. The using of the LTE technology allows reaching maximal transmission speed up to 300 Mb/s for downlink with occupied 20 MHz bandwidth. To achieve peak data rate of 3 Gb/s with operating bandwidth up to 100 MHz for downlink, Advanced Long Term Evolution (LTE-A) has been developed and released by 3rd Generation Partnership Project (3GPP) [2]. Next opportunity for improving the capacity of the mobile network lays in reduction of the mobile cells size. A traditional cellular network is composed from number of base stations, called eNodeB (eNB) in case of LTE technology. Each eNB transmits and processes its own signal from and to mobile user equipment (UE). In accordance to demands of technologies like LTE, the complexity of eNB is growing and therefore it brings additionally costs and more complex signal processing techniques. These issues have led to changes in the concepts of cellular networks towards the cloud based radio access (C-RAN). The C-RAN was proposed as a power and cost effective solution in particular for small mobile cells to reach the capacity of future mobile networks [3]. Difference between C-RAN and classical traditional cellular system is that C-RAN separates baseband processing units (BBU) from remote radio heads (RRH) and processes the data traffic together in BBU hotel or BBU pool. The C-RAN then leads to the new combination of fronthaul architecture and virtualized network core [4]-[5].

Optical fiber (OF) plays significant role in connection between BBU pool and RRH due to its high transmission bandwidth and low attenuation [6]. Thus a Radio over Fiber (RoF) technique has emerged as suitable and effective way for radio frequency (RF) signals transmission through the OF to a distributed antenna system (DAS) with required performance. The RoF system using polarization division multiplex (PDM) for doubling transmission capacity of the RoF link was demonstrated in [7]. Several studies have been also proposed with digitized Radio over Fiber (DRoF) and RoF in combination with wavelength division multiplexing (WDM) or subcarrier multiplexing (SCM) in order to explore the enlargement of the mobile transmission network [8]. Another capacity extension is exploited by time division multiplexing (TDM) technique. This TDM case studies reached transmission speed 2.5 Gb/s for combination of TDM and WDM with using RoF [9]. In [10], a 10 km LTE-RoF link was proposed and investigated for transmission for eNB cell system. In [11] it was proved that LTE-A technology over DRoF is suitable way to reach high transmission rate between base stations, energy saving and cost

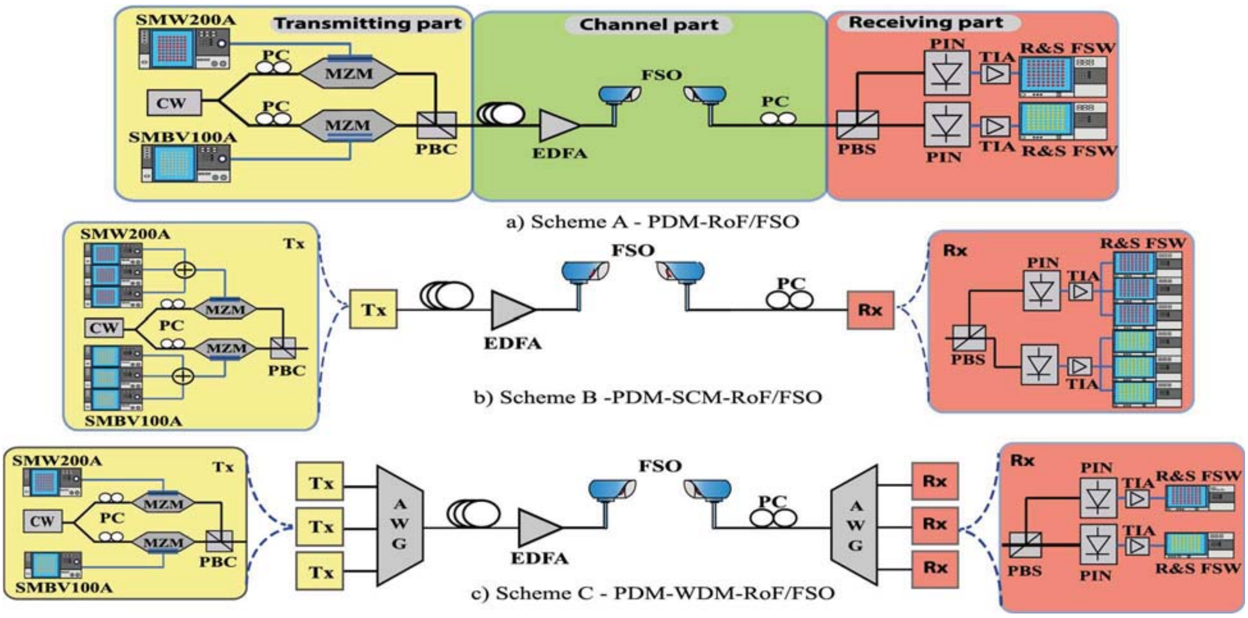


Fig. 1 – Proposed schemes for RoF/FSO test-bed under C-RAN architecture

effectiveness. Moreover, it is very challenging and costly to overcome the last mile by fiber especially in dense urban areas. However, it can be effectively solved by the concept of Radio over Free space optics (RoFSO), which was experimentally investigated together with dual polarization RoF technology in [12].

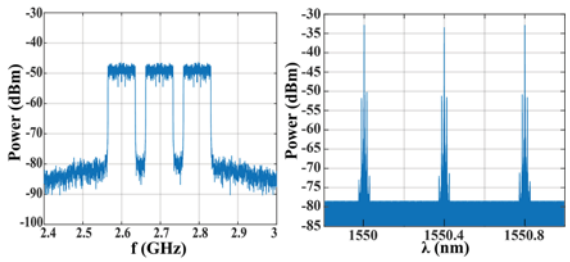
In this paper we provide results from investigation of the combination of analogue RoF and RoFSO system using combined multiplexing techniques in terms of error vector magnitude (EVM). The aim of this paper is to analyze the performance of three schemes: a) scheme A - PDM-RoF/FSO transmission, b) scheme B - PDM-WDM-RoF/FSO transmission and c) scheme C - PDM-SCM-RoF/FSO. The rest of this paper is organized as follows: Section II describes experimental setups of the proposed RoF/FSO schemes performed to validate particular parameters in the network. In the section III the analysis of simulation and experimental results from the proposed C-RAN scheme is given in order to set wider scales of analyzed parameters, and finally the conclusions are presented in section IV.

2. EXPERIMENTAL AND SIMULATION SETUPS

Three setups of analogue RoF/FSO C-RAN proposed schemes are analyzed. The aim is to compare different technologies for transmission of signals between BBU pool and RRH. The experimental setup of all tested scenarios is composed of transmitting part, channel and receiving parts as depicted in Fig. 1. The proposed scheme A (PDM-RoF/FSO) is shown in Fig. 1(a). At the transmitting part the continuous wave (CW) optical source is composed by distributed feedback laser (DFB) COBRITE CBDX4 at wavelength of 1550 nm. Then, the optical output signal is equally divided by a power splitter (PS) and modulated by using of Mach-Zehnder modulators (MZMs). Two signal generators are used for generation of digital radio signals (for upper arm – Rohde & Schwarz (R&S) signal vector generator SMW200A and for bottom arm - R&S SMBV100A). The signals from the generators are optically modulated by MZMs. In order to set appropriate orthogonal polarization states of modulated signal we used two polarization controllers (PC) whose outputs are combined in the polarization beam combiner (PBC) and launched into standard single mode fiber (SMF) G.652.D. In the set-ups the SMF length corresponds to the maximum which can be typically reached according to [13] within C-RAN infrastructure in urban areas. The output signal from SMF is amplified by Erbium doped fiber amplifier (EDFA) to compensate loss and gain sufficient power budget. Afterwards, the amplified signal is passed via an FSO link – both FSO transceivers composed of graded-index lenses (Thorlabs 50-1550A-APC) with an aperture of 1.8 mm and convex lenses with a diameter of 25.4 mm. The parameters of the channel part are then summarized in Table 1. Once the FSO is collimated in the receiving part, a polarization beam splitter (PBS) split the signal into two perpendicular polarization states by appropriate adjustment of PC. The optical signal for each arm is detected by a New Focus PIN photodetector (1544-B-50 with responsibility of 0.6 A/W) and finally converted into electrical domain and amplified by transimpedance amplifier (TIA) with bandwidth 12 GHz. The received signals are processed via the signal and spectrum analyzer R&S FSW for further analyses.

TABLE I. PARAMETERS OF CHANNEL PART

Parameter	Scheme A	Scheme B	Scheme C
Power of EDFA	7 dBm	10 dBm	10 dBm
Length of SMF	25 km	25 km	25 km
Length of FSO	2 m	60 m	60 m



a) b)

Fig. 2 – a) RF Spectrum of PDM-SCM-RoF/FSO and b) Optical spectrum of PDM-WDM-RoF/FSO

In these experimental set-ups we adopted the E-UTRA test model TM2 [14], which has been designed for testing the total power dynamic range using 64 quadrature amplitude modulation (64-QAM). In these set-ups the upper transmission arm is defined by a 20 MHz bandwidth, ensuring maximal transmission speed of LTE, and a carrier frequency at 2.6 GHz, which is commonly used in the urban areas. In the bottom arm we use an independent digital mobile radio as typical case of a distinct service for mobile users. The parameters of the digital mobile radio signal match with the LTE signal in the following points: bandwidth 20 MHz, carrier frequency 2.6 GHz and 64-QAM modulation. In our experiment we focus on the LTE arm as the most challenging part and the second digital radio signal is used for verification of the polarization multiplexing.

The scheme B (based on PDM-SCM-RoF/FSO) is depicted in Fig. 1(b). In this scheme the transmission part comprises three different channels of 20 MHz TM2 LTE signals: In these channels the first subcarriers starts at 2.6 GHz with subcarrier spacing of 10 MHz as shown in Fig. 2(a). On the other arm three independent digital mobile signals with the same TM2 LTE parameters are comprised. The parameters of the channel part are summarized in Table 1. At the receiving part the signals are detected by a PIN photodetector + TIA the same way as described previously, and each detected subcarrier is filtered by a bandpass filter (BPF) to be processed by FSW analyzer.

The scheme C (PDM-WDM-RoF/FSO) is depicted in Fig. 1(c). This scheme uses the same three transmitting parts like in case of PDM-RoF/FSO to increase the overall capacity over the FSO channel. However, each subcarrier is transmitted via an independent wavelength with grid spacing 0.4 nm, as can be seen in Fig. 2 b). These subcarriers are multiplexed by Array waveguide grating (AWG) with insertion loss 3 dB and the PDM-WDM optical signal passes through the channel part defined by Table 1. Finally, the optical signal at the receiver part is divided by AWG into three arms and processed by FSW analyzer.

3. RESULTS

Figure 3 shows the comparison of EVM dependencies on output power of the DFB laser for simulated and measured data of the proposed PDM-RoF/FSO scheme without consideration of turbulence and other atmospheric fading effects. In this scheme the insertion losses 13 dB and 15 dB were measured for transmission parts and FSO channel, respectively. Black dashed line represents EVM limit of 9 % for LTE signal modulated by 64-QAM as defined by 3GPP [14]. As a result, the experimental signal EVM values (blue solid line) exceeds EVM limit for optical launch power (OLP) lower than 1.8 dBm. Consequently, this value was considered the minimum OLP for the system settings. On the other hand, a simulation model based on those proposed schemes was developed to extend RoF/FSO characterization. Furthermore, the comparison of measured and simulated EVM data for the first scheme confirms the degradation pattern, as shown in Fig. 3. In this case, the maximum EVM deviation between both sets of values for OLP 0 dBm is around 1 %.

In order to evaluate the performance of the proposed schemes over a typical last mile FSO link, the channel length was extended from 2 m, under laboratory conditions, to 60 m using 100 mm receiving aperture and studied under simulated conditions. The compensation of attenuation caused by extended FSO part was reduced by increasing EDFA output power to 10 dBm. In this study, the resulting dependency of the proposed PDM-SCM scheme over OLP range values from 0 to 8 dBm is depicted in Fig. 4(a). The EVM results indicate that the first LTE channel located at the lowest frequency reaches the EVM limit for a 2 dBm of OLP. On the other hand, the other two LTE channels are under a similar behavior. For instance, the third LTE channel EVM limit values is located for OLP values around 2.3 dBm.

The EVM results versus OLP for the third proposed PDM-WDM-RoF/FSO scheme from simulated conditions are displayed in Fig. 4(b). Generally, all LTE transmitted channels depict a similar dependence with neglected deviation of ~0.1 % EVM at power value of 0 dBm. In this scheme the EVM limit is related with OLP values around 3.3 dBm. However, this PDM-WDM scheme shows higher EVM values compared with the PDM-SCM scheme due to the AWGs insertion losses.

The proposed and analyzed schemes should be extended to a number of transmission channels, utilization of LTE-A or a more complex FSO channel

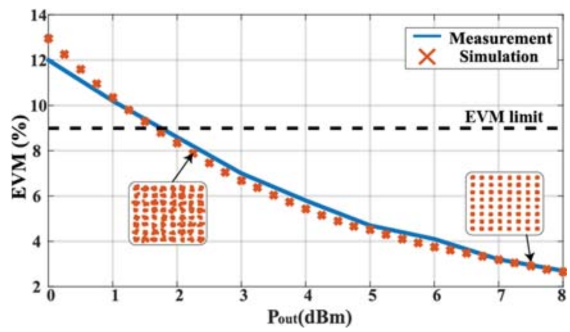


Fig. 3 – The EVM characteristic of PDM-RoF/FSO for various output power of DFB laser. Insets shown simulated received constellation received signal

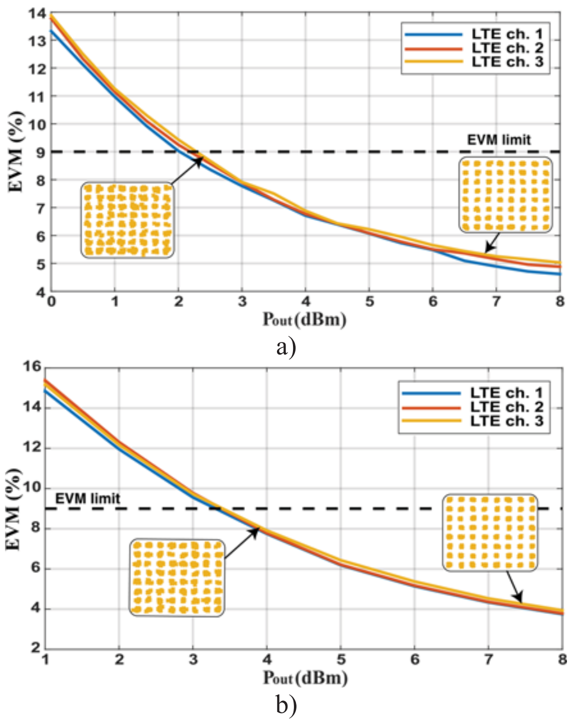


Fig. 4 – The EVM curve vs output power of DFB laser for a) PDM-SCM-RoF/FSO and b) PDM-WDM-RoF/FSO

characterization of atmospheric fading effects for future research. However, the combined RoF and RoFSO distribution for LTE under a C-RAN architecture over FSO channel atmospheric effects was investigated and published by the authors in [12]. It is worth to mention that in such cases the EVM limit for TM2 model is exceed at approx. value of refractive index structure parameter: $C_n^2 = 1.1\,E - 10\,m^{-\frac{2}{3}}$

4. CONCLUSION

In this paper, we have proposed, simulated and experimentally demonstrated the combination of RoF a RoFSO for C-RAN architecture. The characteristics of the experiments were further evaluated in terms of EVM in dependency on various output power of CW laser source. At first step, we measured PDM-RoF/FSO setup and compared with the simulation model. Moreover, the simulation model with maximum deviation of 1 % EVM was used for extending transmission schemes. In this case, two main schemes have been designed in order to test quality of signal in C-RAN. The scheme PDM-SCM-RoF/FSO with 60 m FSO fulfills EVM performance requirements for OLP higher than 2.3 dBm, what corresponds with the maximum EVM limit. In case of the PDM-WDM-RoF/FSO, the EVM limit was passed at minimum output power of 3.3 dBm. PDM-SCM-RoF/FSO evinced to be a suitable variant for implementing in C-RAN architecture, which especially could significantly reduce the future mobile network implementation costs.

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