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Citation for the original published paper:

P. Peseck, J. Bohata, S. Zvanovec and J. Perez, "Characterization of dual-polarization analogue radio over fiber fronthaul for LTE C-RAN architecture," 2016 10th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP), 2016, pp. 1-4, doi: 10.1109/CSNDSP.2016.7573934.

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Characterization of Dual-Polarization Analogue Radio over Fiber Fronthaul for LTE C-RAN Architecture

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Abstract — In this paper the results from extended measurement of dual-polarization (DP) analogue radio over fiber (RoF) in a long term evolution (LTE) cloud radio access network (C-RAN) architecture are presented. This technique is proposed for fiber connections between central offices and remote base stations. Investigation of various optical fiber length is carried out to determine the best system performance in terms of error vector magnitude (EVM) and bit error rate. Maximal achieved distance for the case of LTE bandwidth of 20 MHz is 50 km displaying permissible EVM value of 8.5 % at the radio frequency of 2.6 GHz when using 64 QAM modulation scheme.

Keywords—radio over fiber; dual polarization; long term evolution; cloud radio access networks component;

I. INTRODUCTION

Global mobile data traffic has been exponentially increasing and, according to Cisco forecast [1], it should reach 24.3 exabytes (EB) per month in 2019, which is around four times higher than prediction for year 2016. To satisfy demands of extremely increased mobile data traffic, the 3rd generation partnership project (3GPP) have released long term evolution advanced (LTE-A) technology achieving 300 Mb/s downlink and 75 Mb/s uplink when using 20 MHz bandwidth [2,3]. A novel cloud radio access network (C-RAN) architecture has been proposed to optimize cost and energy consumption based on the fact that the most of the power consumption originates from the cell sites [4]. In C-RAN, baseband processing is centralized and shared among sites in a virtualized baseband unit (BBU) pool or hotel. This baseband network is referred to as fronthaul. The architecture then due to lower amount of BBUs leads to the reduction of the cost of the network operation because of the reduced power and energy consumption compared to the traditional architecture.

Optical fiber has an explicit function in mobile network architectures due to its low attenuation and transmission bandwidth, which goes hand in hand with benefits of the optical fiber backhaul in terms of the power and cost effectiveness [5]. The effective and simple way how to transmit generally radio frequency (RF) signal through the optical fiber infrastructure to a distributed antenna system (DAS)

maintaining properties of the signal, is known as radio over fiber (RoF) technology. This technique can overcome distances from few hundred meters up to tens of kilometers and enables transmission of radio services at frequencies up to approximately 100 GHz [6]. The capacity of the RoF link can be significantly increased by using polarization division multiplexing (PDM), as showed in [7] to transmit orthogonal frequency division multiplexed (OFDM) signals, based on ultra-wide band (UWB) standards, through passive optical networks. The experimental investigation of the analogue RoF system over a 100 km optical fiber using PDM multiple input multiple output (MIMO) LTE-A signals at the RF frequency bands of 2.6 GHz and 800 MHz was demonstrated in [8]. Discussion about deployment costs and energy savings of digital RoF systems for LTE-A is presented in [9] highlighting a cloud solution of BBUs hostelling. Moreover, the RoF technology promises to be a good solution for ultra-small (i.e. femto) cells in 5th generation of mobile networks [9]. In this case, a RoF system constitutes optical backbone for a very dense wireless network. A combination of the fiber and radio transmission within 5G networks is described in [10, 11] where it is proved to be very promising approach for mobile fronthauling, especially for small-cells. The proposed system is investigated in terms of error vector magnitude (EVM) and bit rate throughput highlighting the EVM parameter as an ideal indicator for the reliability of mobile network communication links.

In this paper we investigate in detail an analogue dual polarization (DP) RoF link for the application within a C-RAN LTE network fronthaul architecture. Therefore, an extensive measurement campaign is provided to extend our recently published results [12], where joint technology of RoF and radio over free-space optics (RoFSO) were analysed, especially in terms of optical fiber requirements. This paper is organized as follows: section II introduces description of the experimental setup. Results from the measurements and simulations are then discussed in section III, and finally the conclusions are presented in section IV.

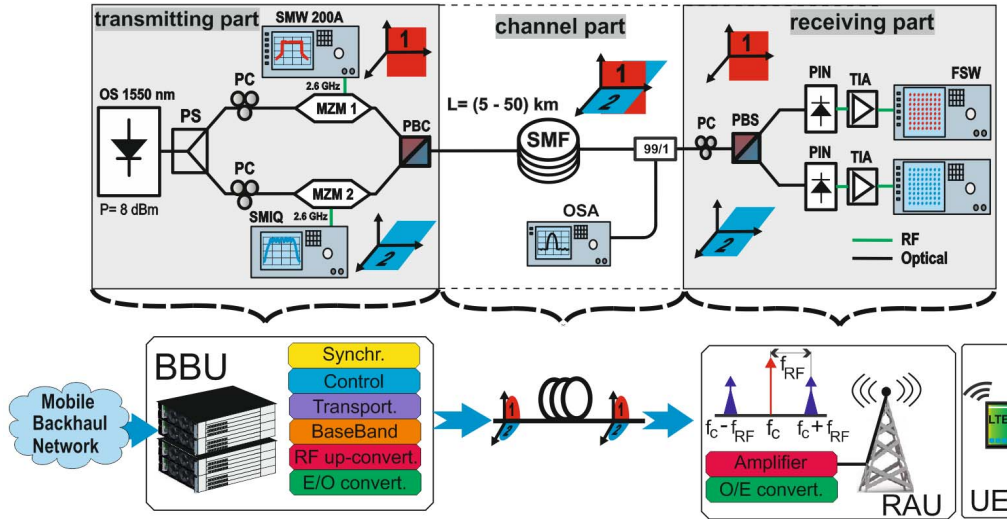


Fig. 1. The schematic diagram of analogue DP-LTE over fiber communications for C-RAN fronthaul architecture (upper part shows laboratory setup; the corresponding network structure is illustrated below).

II. SYSTEM DESCRIPTION

The experimental setup can be divided into transmitting part, channel and receiving part as shown in Fig. 1. Transmitting part contains an optical source (OS), formed by a distributed feedback laser (DFB) at wavelength 1550 nm, and followed by a power splitter (PS), which divides optical power into two branches. Optical carriers are initially adjusted to each PDM channel via polarization controllers (PC) and then modulated by two independent RF signals at the same frequency by using Mach-Zehnder modulators (MZMs). The modulated signals are combined and deployed into the optical domain via polarization beam combiner (PBC) to form DP RoF. In this case two RF generators are used to modulate optical carrier via MZMs - R&S LTE generator SMW 200A and digital signal generator R&S SMIQ. The optical channel part is formed by single mode fiber (SMF) G.652.D (tested variable lengths) and followed by coupler, which couples 1 % of the optical signal to OSA for monitoring of optical signal-to-noise ratio (OSNR). In the receiving part, the polarization orthogonality is controlled by PC and then a polarization beam splitter (PBS) is used to split lightwave into two independent polarization branches. Each branch is then detected by using New Focus PIN photodiode (type: 1544-B-50 with responsivity of 0.6 A/W) and amplified by transimpedance amplifier (TIA). The detected signals are evaluated and processed in a signal analyser R&S FSW. For further analysis, we focused on the LTE part only.

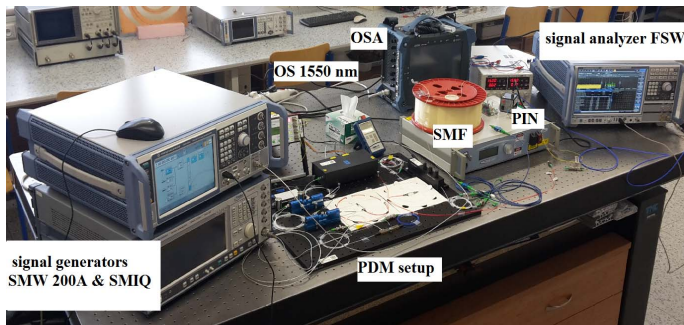


Fig. 2. Laboratory experimental setup at CTU, Prague.

In our experimental setup (see Fig. 2), we used E-UTRA test model TM2 [13], which has been adopted for channel testing with the variable bandwidths 1.4, 3, 5, 10, 15 and 20 MHz at frequency of 2.6 GHz and deployed into one polarization branch. The test model includes 64 quadrature amplitude modulation (64-QAM) scheme for testing of the total power dynamic range. In the second, orthogonally polarized branch, an independent digital mobile radio service was transmitted in parallel to the LTE signal for validation of the PDM scheme. In this case, signal was modulated by digital 64-QAM with constant bandwidth of 20 MHz having the same carrier frequency of 2.6 GHz, as the LTE signal, in the other branch. The output power from OS was set to 8 dBm in order to achieve sufficient power budget within the whole system while using different SMF lengths. In addition to avoid inter-modulation products of the system maintaining transmission characteristic, the signal generators' output RF power was fixed to optimal value of 0 dBm.

III. EXPERIMENTAL RESULTS

The DP LTE transmission was evaluated for variable distances between the central office and the remote access unit (RAU) ranging from 5 km to 50 km, at 2.6 GHz using selected bandwidths, as shown in measurement schematic diagram in Fig. 1. The measured results in terms of EVM dependence on LTE bandwidth for different SMF fiber lengths are depicted in Fig. 3. We can see almost linear increase of measured mean EVM value with widening of the LTE bandwidth for all SMF lengths. Red dashed line represents EVM limit of 9 % for reliable transmission and high data rate 64 QAM modulation scheme [13]. In the case of the maximal bandwidth of 20 MHz and a 50 km long SMF, the EVM reaches approximately 8.5 %, which is very close to the tolerable limit. The difference between 10 MHz and 20 MHz bandwidth is expressed approximately by 2 % variation of EVM in case of 50 km link. The degradation of the EVM is mostly caused by the non-compensated chromatic dispersion (CD) at wavelength of 1550 nm.

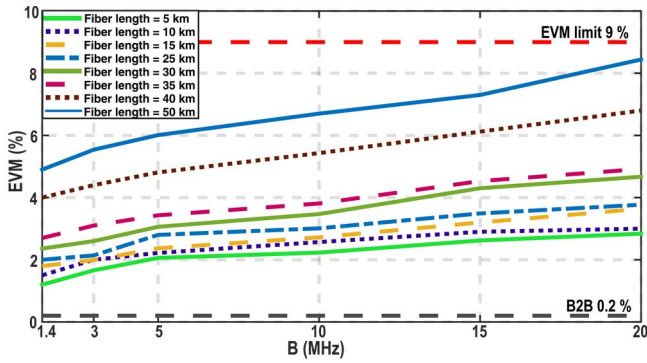


Fig. 3. The experimental EVM results of selected LTE bandwidths for particular SMF length

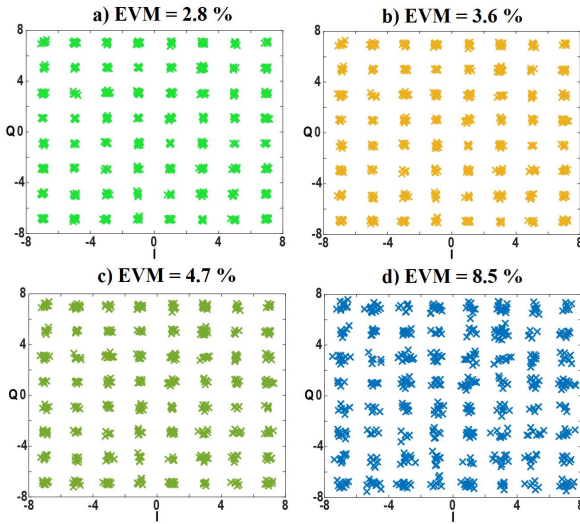


Fig. 4. The constellation diagrams for 20 MHz bandwidth and length of the SMF a) 5 km b) 15 km c) 30 km and d) 50 km

Furthermore, the proposed system evinces very good performance in terms of minimal EVM values up to SMF length of 35 km without need for additional optical amplifier. The EVM is less than 3 % at bandwidth 1.4 MHz and less than 5 % at 20 MHz. The experimental results indicate that the use of erbium doped fiber amplifier (EDFA) would overcome much longer link distances or improve the EVM values. The improvement of EVM about 2.5% is reached with exploiting of EDFA for 35 km long SMF with 20 MHz LTE bandwidth. The related measured constellation diagrams for bandwidth of 20 MHz for particular SMF lengths of 5, 15, 30 and 50 km are shown in Fig. 4. They clearly illustrate the increase of EVM from 2.8 (for 5 km link) up to 8.5 % (50 km link).

The bit error rate (BER) magnitude values [14] obtained from the experimental results of the proposed LTE RoF C-RAN fronthaul architecture are shown in Fig. 5 in dependence on the fiber length for particular bandwidths. Three curves representing bandwidths of 1.4 MHz (blue), 10 MHz (dark red) and 20 MHz (yellow) illustrate the typical LTE utilization. Red dashed line demonstrates the above mentioned limit for high data rate and reliable transmissions. The best performance is achieved with the lowest bandwidth (1.4 MHz) which reaches BER $1E-10$ threshold for fibers up to 38 km, followed by 10 MHz and 20 MHz bandwidths reaching BER $1E-10$ till 30 km and 19 km fiber lengths, respectively. The EVM limit 9 % corresponds after recalculation to BER $4.5E-3$ for 64 QAM [14].

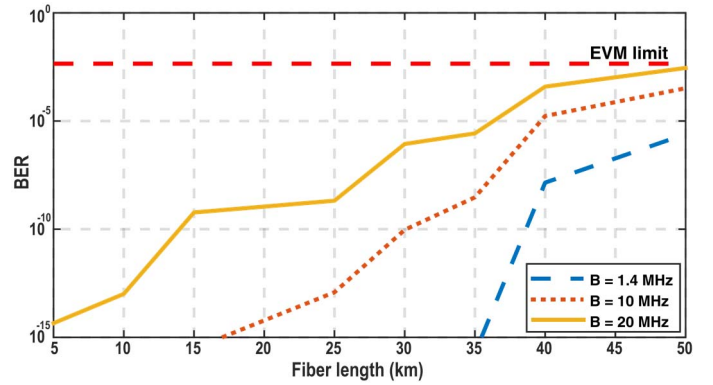


Fig. 5. The BER characteristic of proposed system for various bandwidth and SMF length

Furthermore, the flexibility of the proposed system can be improved by combination of the optical wire and optical wireless transmission. In 5G networks, the free space optics (FSO) technique is being taken into consideration to be adopted for C-RAN backhaul, as the substitution of the optical fiber, offering extremely high data rate comparable to wireless RF [15]. The utilization of combined FSO and fiber LTE C-RAN backhaul was experimentally proposed in [12]. Please note that in the case of combined RoF and RoFSO C-RAN system designers have to consider a margin for EVM degradation due to the turbulences and other atmospheric fading effects. The change of EVM can exceed the limit of 9 % for 64-QAM as it was tested for the setup combined SMF+EDFA+FSO under turbulence (in terms of refractive index structure parameter evincing value of $C_n^2 = 1.5E - 10 m^{-2/3}$). In such a case, the reachable limit of the fiber infrastructure is considerable reduced towards shorter link distances or it has to be planned utilization under limited bandwidth, as investigated in [12]. This feature should be treated very precisely in future research activities.

IV. CONCLUSION

The DP analogue RoF link transmitting 3GPP LTE signal in C-RAN fronthaul architecture was evaluated. The proposed system evinces the maximal achievable distance of 50 km (without EDFA) while using 20 MHz bandwidth and exhibiting 8.5 % of EVM, which is bellow EVM threshold limit 9 % for used 64 QAM modulation scheme. Furthermore, we have not observed a significant difference in the DP RoF link performance for distances from 5 km to 35 km without the using of EDFA, which makes the system more simple and cost effective. The obtained results provide extended features to planning C-RAN LTE over fiber and FSO networks.

ACKNOWLEDGMENT

The measurement was supported by CTU project SGS14/190/OHK3/3T/13 and join cooperation was supported by EU COST Action OPTICWISE (IC 1101). J. Perez's work is supported by Spanish MINECO Juan de la Cierva Fellowship JCI-2012-14805.

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