Analog optical links for 5G fronthaul networks

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***Abstract*— Addressing bandwidth limitation in the fronthaul segment of next generation 5G network has become nowadays an important problem in the data communication community. Radio over Fiber together with Spatial Division Multiplexing has been recently proposed as the suitable technologies to implement the fronthaul network segment. In this work, we address this topic studying experimentally analog optical links for 5G communications.**

Keywords—Microwave photonics, Radio over Fiber, mobile optical communications

I. Introduction

Information and Communication Technology (ICT) systems are expanding at unprecedented rate in terms of capacity demands, number of connected users and required infrastructure. Global mobile data traffic grew 74 percent during 2015 to reach 3.7 exabytes per month worldwide, and recent forecast predicts an increase of data traffic up to 30.6 exabytes per month by 2020 [1]. Furthermore, as the majority of all traffic from mobile-connected devices is offloaded to the backhaul and into the core network, there will be a real bottleneck in terms of bandwidth capacity. The direct result is that similar traffic growths and bandwidth bottlenecks are predicted to the fronthaul networks (see Fig. 1) and the datacenters [2].

Then, it will be required that the bandwidth capacity will be increased by a factor higher than 1000. The new emerging scenarios are 5G mobile communications[3]-[4], and Internet of Things (IoT)[5] using in particular mobile networks based on small cells (femto-cells) and the millimeter wave (mmWave) spectrum in the wireless access. However, to achieve the target bandwidth, these solutions require a reduction of the size of the cells to get a better spectrum efficiency, leading to a drastic increase of the cost and makes it difficult the management of the network. Furthermore, scaling to the mmWave part of the microwave spectrum (~40GHz) permits to access a higher potential bandwidth, but the cost of transceivers increase, and as they are located next to radiation elements, the maintenance cost also increase. Additionally, the fronthaul network is not going to be able to provide expected bandwidth of 5G because it is usually copper data link based.

Therefore, following the experience of the Datacom industry in the last decade to push towards optical links, the fronthaul network should move to a low cost and reliable optically based communication network using a new approach to reach data rates in the order of Petabits/s. Unfortunately, the bandwidth requirements cannot be achievable by just using Wavelength Division Multiplexing (WDM) techniques or complex modulation formats because a minimum of hundreds wavelengths may be required which is not scalable on chip. Spatial Division Multiplexing (SDM) together with Radio over Fiber (RoF) has been recently proposed as the best suited solution for implementing 5G fronthaul networks. Indeed, the RoF solution is a promising solution to increase the capability of the network in terms of bandwidth and reducing link loss. RoF overcomes the problems associated to reducing cell sizes and scaling to the mmWave spectrum. RoF may enable to centralize all the data treatment on the Central Office, giving flexibility on the management of the network and reducing maintenance and deployment costs. Furthermore, the use of SDM is proposed as an additional multiplexing technique to further increase the bandwidth capabilities [6]-[7]

In this work, we demonstrate the optical transmission and generation of analog RF mobile signals in the mmWave band. The proposed system can be used for the transmission of 5G-NR waveforms.

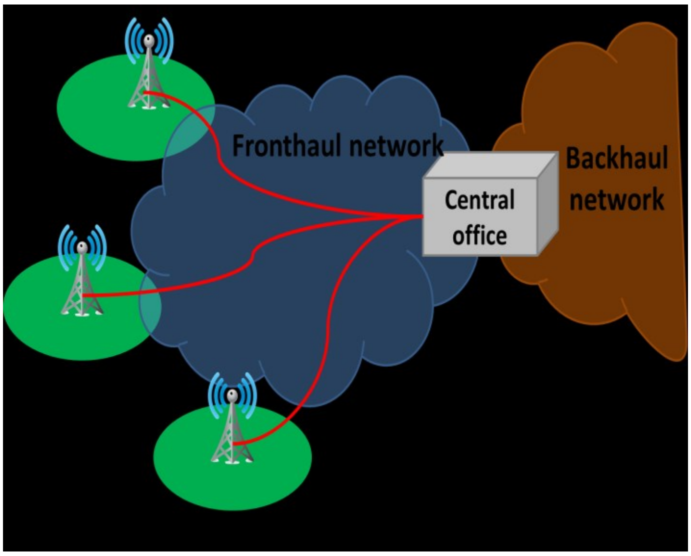

Fig. 1. Schematic view of the fronthaul network in a mobile communications network

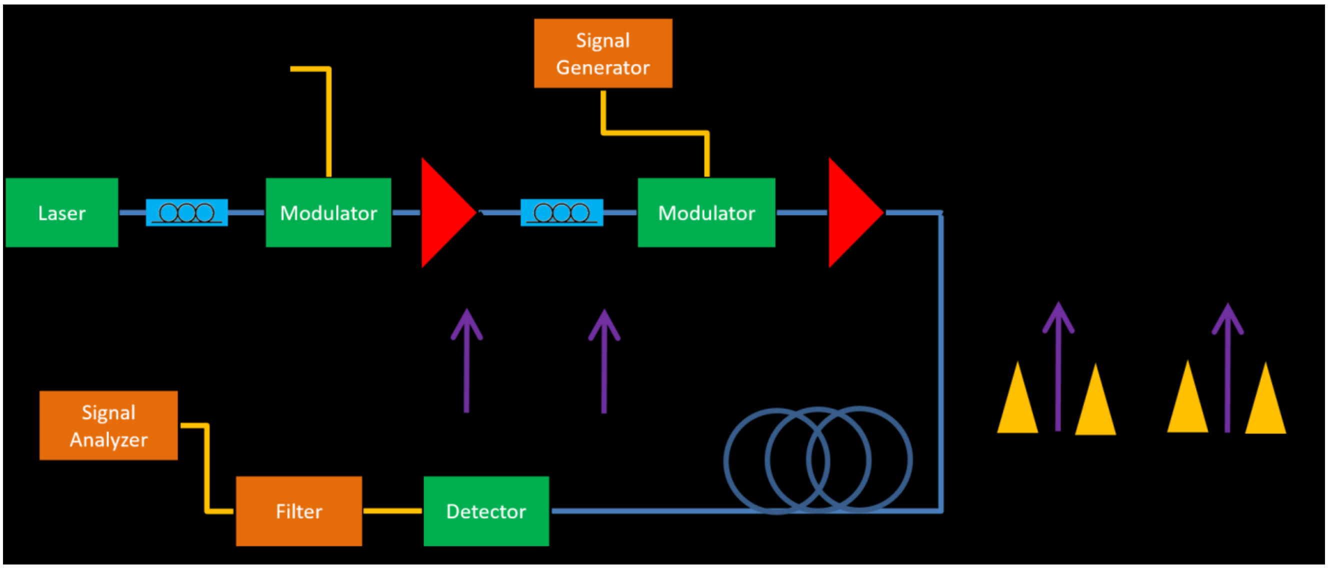

Fig. 2. Experimental setup.

II. EXPERIMENTAL SETUP

The experimental setup used for the mmWave RoF link is sketched in Fig. 2, showing the theoretical spectra of the mmWave optical signals. The generation of the mmWave optical signal is based on combination of double side band (DSB) and optical carrier suppressing (OCS) modulation techniques. The targeted RF frequency for transmission is 26.5GHz. In order to generate the RF signal, firstly, a laser was modulated by a 15GHz sinusoidal oscillator using an OCS approach. A Mach-Zehnder Modulator (MZM) biased in the null point was employed to implement the OCS modulation. The theoretical output spectrum is sketched in Fig. 2, it consists on two tones separated 30GHz in frequency. After the modulator, an Erbium Doped Fiber Amplifier (EDFA) is included to partly compensate for the modulator loss. The two tones are then fed to a second MZM biased in the quadrature point. An RF signal emulating the user data is used as modulating signal in the second MZM. We used the Rohde & Schwarz SMW200A as signal generator. The considered output constellation diagrams were 256QAM, 128QAM, 64QAM, 32QAM, 16QAM and QPSK, and the maximum symbol rate of the equipment was 500MSps.The RF output of the signal generator was centered in frequency at 3.5GHz. After the modulator the signal was amplified again to compensate for the insertion loss of the modulator and propagated through 10Km of single mode fiber. The spectrum of the signal sent though the fiber is depicted in Fig. 2. After the 10Km long fiber, the signal is detected using a single high-speed photodiode. The optical signal is then converted to mmWave domain. After the detector there is the presence of two different beatings, one centered at 33.5GHz and another at 26.5GHz. In our experiment we focused on the detection of the signal centered at 26.5GHz. The contribution at 33.5GHz is filtered out in the RF domain. The received signal is then fed to the Rohde & Schwarz FSW43 signal analyzer, where the quality of the signal was evaluated. Bit Error Rate (BER) of the received measured was evaluated. The characteristics of the components used in the experimental setup are summarized in Table I. A TUNICS T100S-HP external cavity laser was used as an optical source, for MZM1 we used the MX-LN-40 LiNbO3 intensity modulator of Photline. The Miteq phase-locked coaxial resonator oscillator BCO-10-15000-315P was used for the 15GHz sinusoidal tone. For the MZM2 a LiNbO3 intensity modulator from JDS Uniphase was employed. Finally, the Finisar XPDV2320R dual band high-speed photodetector was used as receiver.

TABLE I. COMPONENT PARAMETERS

Parameter	Value
Laser power	10dBm
MZM1 insertion loss	4dB
MZM1 half-wave voltage	6V
MZM1 Bandwidth	30GHz
15GHz oscillator power	13dBm
EDFA1 gain	20dB
MZM2 insertion loss	5dB
MZM2 half-wave voltage	6.8V
MZM2 Bandwidth	15GHz
EDFA2 gain	20dB
Photodiode Responsivity	0.65A/W
Photodiode Bandwidth	50GHz
Photodiode optical return loss	27dB

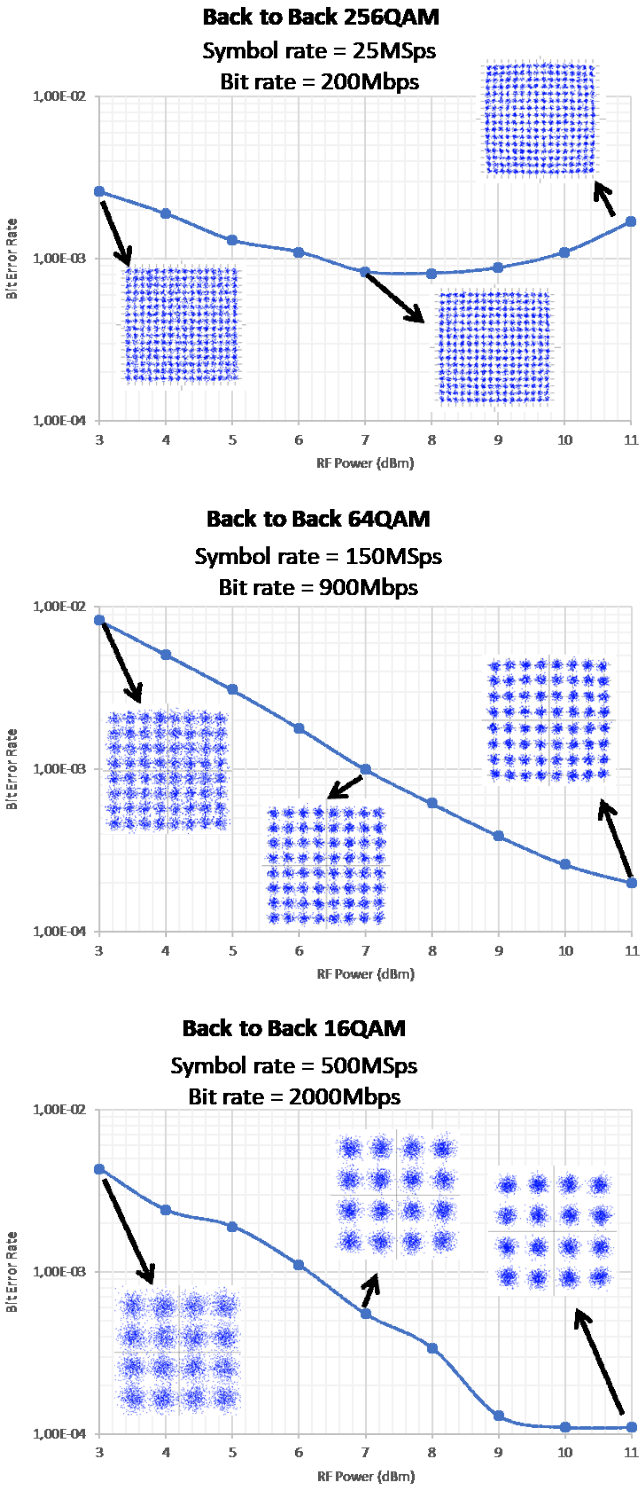

Fig. 3. BER performance of the system for 256QAM, 64QAM and 16QAM in back to back configuration.

III. Measurements

In order to evaluate the performance of the system, measurements in back to back configuration (without the 10Km long fiber) were also performed. Firstly, the link gain was estimated to be around -60dB. The output power of the signal generator was initially fixed to 7dBm, then for each modulation format the symbol rate was adjusted to get a BER performance of 10^{-3}, limit for forward error correction (FEC). Afterwards, for each modulation the output power was swept from 3dBm to 11dBm and the BER was recorded for each point. A summary of the results is shown in Fig. 3, where the BER as a function of the output RF Power is represented along with some examples of the received constellation diagrams. The link was not limited by fiber dispersion but by signal to noise ratio. The maximum symbol rate achieved for 256QAM was 25MSps (200Mbps), 45MSps (315Mbps) in the case of 128QAM. In these two cases, due to the high density of the constellations the received constellation diagrams at high power (11dBm) clearly exhibit nonlinear distortion. In the case of 64QAM the maximum symbol rate was 150MSps (900Mbps), and 300MSps (1500Mbps) for 32QAM. The symbol rate limit of the equipment was reached for the 16QAM transmission (2000Mbps).

However, after the transmission through the 10 Km single mode fiber the maximum symbol rates are reduced. A summary of the results is presented on Fig. 4, similar trends are observed as for the previous case but for a lower symbol rate. 16MSps transmission was obtained for 256QAM case (128Mbps). In the case of 128QAM a maximum symbol rate of 27MSps (189Mbps) was obtained. 45MSps was the maximum symbol rate for 64QAM (270Mbps). For 32QAM transmission up to 55MSps (275Mbps) was possible. 150MSps data transmission was possible for 16QAM (750Mbps). Finally, in the QPSK case the maximum symbol rate was limited by the equipment, reaching the 500MSps (1000Mbps).

IV. Conclusion

Optical generation of RF mobile communication signals in the mmWave spectrum have been explored experimentally. This approach has been used to demonstrate RF optical links of 10km distance with up to 1000Mbps data rate for a BER below 10^{-3}.

Acknowledgment

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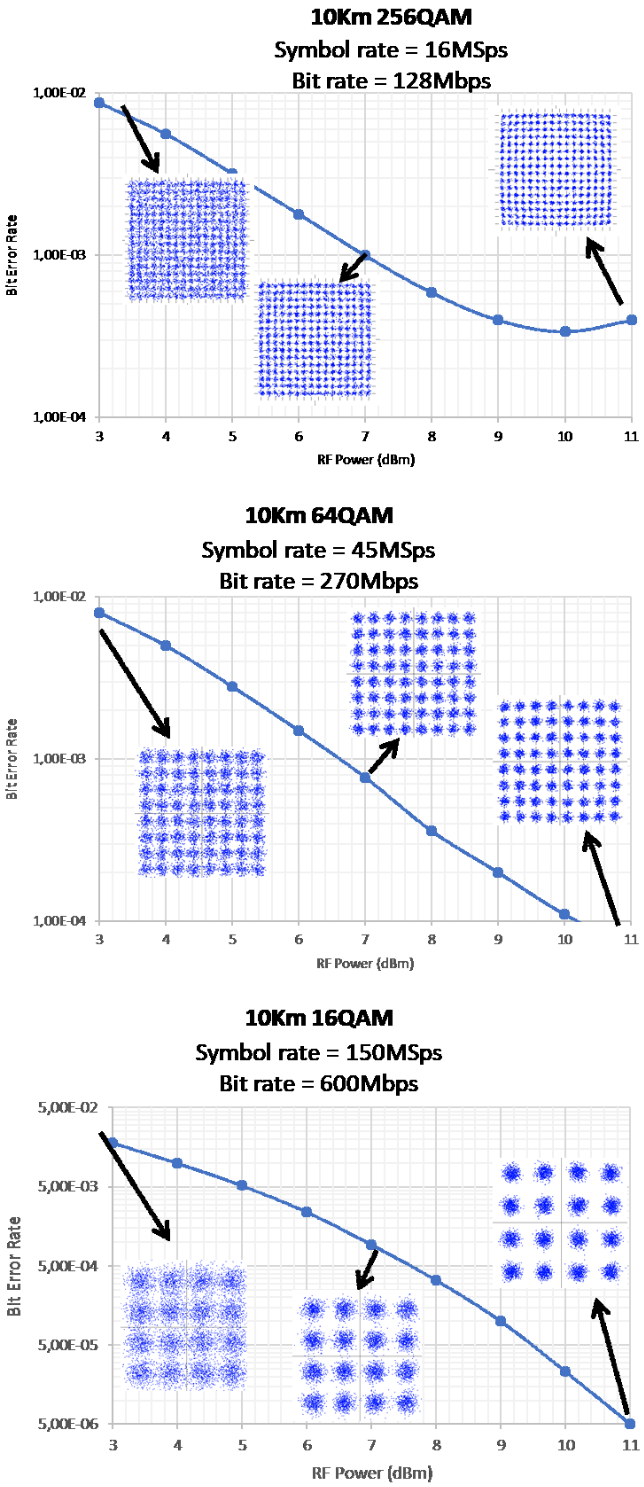

Fig. 4. BER performance of the system for 256QAM, 64QAM and 16QAM after propagation through 10Km of single mode fiber.

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