50 Gbit/s/λ WDM Real Time Transmission in Hollow Core Antiresonant Fiber reaching 42.3 dB Optical Budget for Mobile X-Haul

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Abstract *A WDM transmission at 50 Gbit/s/λ in real-time over 6 wavelengths (one λ modulated at a time) over a hollow core anti-resonant fiber is performed. An optical budget of 42.3 dB is reached when a single wavelength is transmitted with a booster EDFA.*

Introduction

Optical Fiber access To The Antenna, the so-called FTTA, is a mature concept and mainly deployed for mobile backhaul and fronthaul Radio Access Network (RAN) [1]. For mobile backhaul, this 20 km reach network segment typically is defined between the central office and the radio tower though a Point-to-Point (PtP) link between Optical Line Terminal and the cell site gateway. Optical fiber provides an efficient cost and power consumption solution to transmit a mobile traffic at 10 & 25 Gbit/s for 5G (in fact the traffic aggregation of all mobile generations up to 5G) while 100 Gbit/s or more are expected for 6G [2], [3]. For mobile fronthaul, the network segment is defined between Digital Unit (DU) and Radio Unit (RU). This link could be as short as the distance (<2 km) between the top and bottom of the radio tower also named Distributed RAN. This link could be also extended to about 20 km between the top of the radio tower and a central office which hosts the DUs. In this case, the use of limited number of fiber is required by using a multiplex of these fronthaul interfaces. Optical fiber interface allows to decrease RAN power consumption about 50% by avoiding long coaxial cable (Radio Frequency losses) and so optimizing the RU's power consumption to deliver the adequate RF power close to the antenna. Each radio tower sector (typically three) requires a RU per radio technology. So, fronthaul network is a combination of several fronthaul parallel links working each at up to 25 Gbit/s for up to 5G and expected 100 Gbit/s or more for 6G. To optimize fiber deployments, Wavelength Division Multiplexing (WDM) is often used for mobile fronthaul or backhaul [4].

While bandwidth is a major challenge, latency is another one for fronthaul and backhaul. For 6G, approximately 1 ms or less end-to-end latency is targeted with 100 µs for the air interface. These values are ten times lower than in previous RAN generation (10 to 1 ms). Optimization at different levels of the network must be found to reach this latency objective. For optical fiber infrastructure, a hollow core fiber is a candidate solution by decreasing transmission latency from 5 to 3.3 µs/km [5], [6], the latter being really close to the fundamental limit of the speed of light in vacuum. Typically for a reach of 20 km either fronthaul or backhaul, 34 µs latency could be saved. We assess in this paper the feasibility for a single or multiple PtP interfaces working at 50 Gbit/s. Hollow core fiber was already propose in the context of the fronthaul [7]. In this work, we perform a WDM transmission at 50 Gbit/s/λ in real-time over a hollow core anti-resonant fiber.

Single wavelength measurements

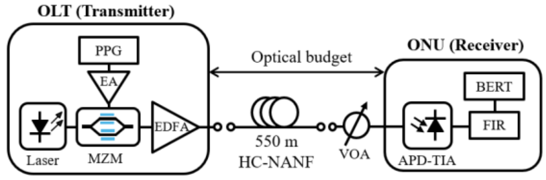

Fig. 1: Experimental setup.

The experimental setup is depicted in Fig. 1. The optical signal is generated by a tunable laser emitting in C-band. The signal is modulated by a 40 GHz electro-optical bandwidth (EO-BW) Mach-Zehnder Modulator (MZM). A 50 Gbit/s Non-Return to Zero (NRZ-OOK) electrical signal is generated by a Pulse Pattern Generator (PPG) using a Pseudo Random Bit Sequence (PRBS of length 2^{15}-1). This electrical modulation signal is amplified by an Electrical Amplifier with 30 dB gain before driving the MZM. The modulated optical signal passes through an Erbium Doped Fiber Amplifier (EDFA) with 24.8 dB gain. The launched optical power into the link is equal to 19 dBm at 1528.7 nm. The signal propagates into a 550 m long Hollow Core Nested Antiresonant Nodeless Fiber (HC-NANF). A Variable Optical Attenuator (VOA) is inserted to emulate the losses. The optical signal is detected using a Germanium on Silicon Avalanche Photodiode (APD) coupled with a TransImpedance Amplifier (TIA). The assembly APD-TIA shows an EO-BW of 25 GHz. An analog 6-taps Finite Impulse Response (FIR) filter with a 64 GHz analog bandwidth is used to prevent the bandwidth limitation of the APD.

The HC-NANF was designed and manufactured in−house by Photonics Bretagne for this work. Its geometry was first defined by computer simulation to maximize optical transmission in the C-band. The well-known stack-and-draw technique was applied to fabricate the preform. After fiber drawing, the geometry was analysed by Scanning Electron Microscope (SEM) and compared to the model (see fig 2) to isolate the best fiber batch. Attenuation measurement, based on the cut-back method, was used to complete the optical characterization. To facilitate the implementation of the hollow core antiresonant fiber in the experimental setup, the HC-NANF is interconnected with a standard single-mode fiber (SMF-28) at each end. To adapt the mode field diameter between the HC-NANF and the SMF connected with an FC connector to minimize insertion loss, segments of a graded-index fiber, specially designed and manufactured by Photonics Bretagne, are inserted between the fibers.

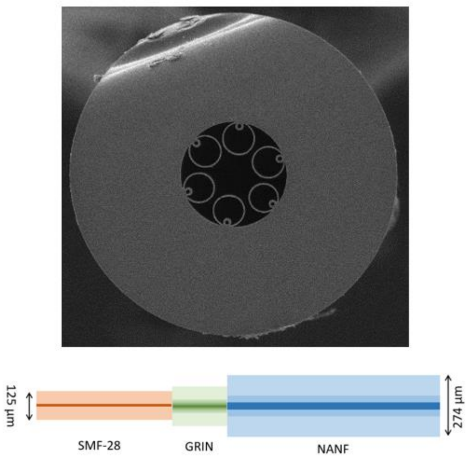

Fig. 2: Picture by SEM of the NANF achieved for this work and compliant with the following dimensions D_{core} = 33 µm; $d_{capillar}/D_{core}$ = 0.75; $d_{nested}/d_{capillar}$ = 0.21; $t_{capillar}$ = t_{nested}. Scheme of principle of the interconnection between the HC-NANF and SMF-28 using a segment of graded-index fiber (GRIN). (below)

The optical BW of the HC-NANF is shown on Fig. 3. The BW is measured by using a white light source (red curve) and measuring the signal at the output of the HC-NANF (blue curve). The ratio of the input and the output, give the BW of the HC-NANF (yellow curve). The BW of the HCF is centred at 1550 nm and have a 3 dB width of 175 nm.

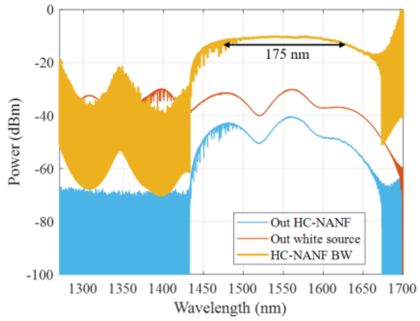

Fig. 3: Optical spectrum measurement at the output of the white source (red), at the output of the HC-NANF (blue) and resulting bandwidth of the HC-NANF (orange).

This HC-NANF does not allow transmission in the O−band which is commonly preferred in latest high speed optical access networks.

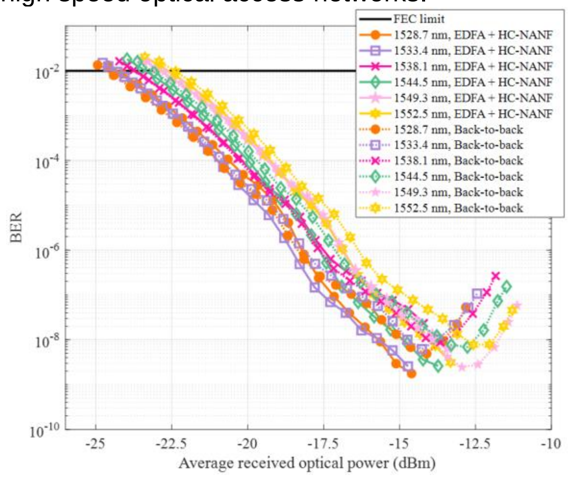

Fig. 4: BER as function of the average received optical power.

We consider in this work multi-channel transmission in this HC-NANF based on a Dense WDM technique. The wavelengths of the considered channels are: 1528.7 nm, 1533.4 nm, 1538.1 nm, 1544.5 nm, 1549.3 nm and 1552.5 nm. First, we assess the single wavelength behavior of our test bench. Fig. 4 presents the BER versus the average received optical power the 6 channels transmitted in back-to-back and with booster EDFA and propagation in the HC-NANF. Depending on the channel, we observe a sensitivity between −24.8 and −22.4 dBm. We do not observe any degradation of the sensitivity in back-to-back or with EDFA and HC-NANF revealing good single mode properties of the fabricated fiber. The launched power with only one signal in the EDFA depends on the wavelength. The highest launched power is for the channel at 1528.7 nm and the lowest on the channel at 1552.5 nm. The values are respectively 17.5 dBm and 16.9 dBm. These high launch power values can be launched in a HC−NANF without detrimental non linear effect, as the signal propagation medium is the air as demonstrated notably in [8]. It leads to an optical budget of 42.3 dB at 1528.7 nm and 39.3 dB at 1552.5 nm. These results exceed specifications of every optical budget class for PtP and WDM standards [9], [10].

WDM transmission

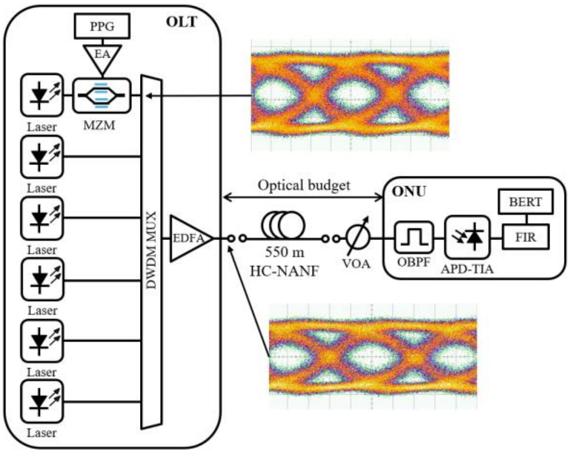

Fig. 5: WDM experimental setup.

The WDM capabilities of HC-NANF in C-band has been proved in [8]. We now assess the capability of the link to support the evolution of mobile X-Haul at up to 100 Gbit/s per antenna site. The scenario studied in this part is an optical WDM link connecting the 3 radio sectors for 360°coverage of an antenna site with macro-cells. Each sector will require 100 Gbit/s for 6G X-Haul so two WDM channels at 50 Gbit/s are needed per sector. For the 3 sectors, a total of 6λ is required for bidirectional transmissions. The experimental setup shown on Fig. 1 is updated on Fig. 5 to allow WDM transmission.

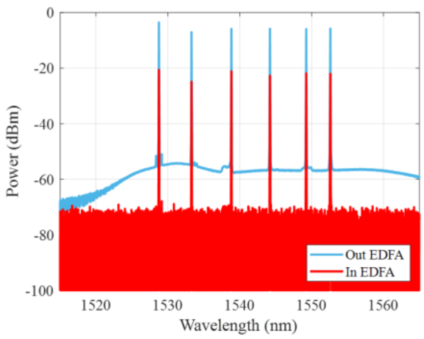

Fig. 6: Optical spectrum of the WDM signal before and after EDFA.

Six laser sources are now used at the transmitter side. Due to limited lab capacity, only one channel is modulated and carrying data. The 6 optical signals are multiplexed using a Dense Wavelength Division Multiplexing Multiplexer (DWDM MUX) with 100 GHz spacing. An Optical BandPass Filter (OBPF) is also inserted, it is used to select the wavelength to be detected at the receiver. The bandwidth of the OBPF is equal to 4 nm and the losses to 3 dB. The spectrum of the WDM grid at the output of the MUX and at the output of the EDFA is shown on Fig. 7. The flatness of the WDM grid is lower than 4 dB. The channel with the lowest wavelength sees a slightly higher gain due to the peaking in the ASE spectrum of the EDFA.

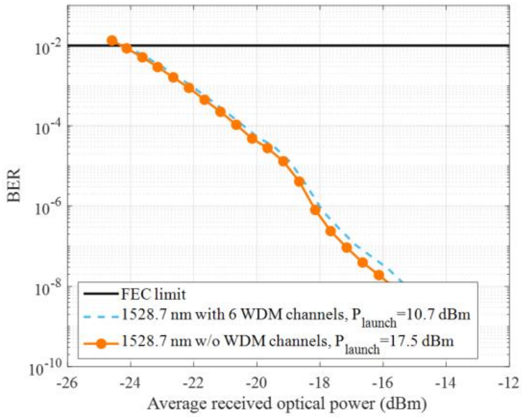

Fig. 7: BER as function of the average received optical power for 1528.7 nm channel with the presence and without all the WDM grid.

The BER measurements are presented on Fig. 8. The solid line curve in orange comes from the EDFA+HC-NANF measurements from Fig. 4. The dashed blue curve shows the BER as function of the average received optical power for 1528.7 nm. No degradation of the sensitivity (−24.5 dBm) of the receiver appears when all the channels are inserted in the EDFA. However, a degradation of the optical budget can be observed because, in WDM operation, the gain of the amplifier is shared among all the channels. The launched power of the signal at 1528.7 nm is equal to 10.7 dBm instead of 17.5 dBm in single wavelength operation. We also must consider the losses of the OBPF. The optical budget is now equal to 32.2 dB (42.3 dB with a single wavelength). This value is still well above the standard (20 dB at 25 Gbit/s).

Conclusion

We experimentally demonstrate in real-time both single wavelength and WDM transmission of 50 Gbit/s/λ NRZ channels through a 550 m-long hollow core antiresonant fiber. An optical budget of up to 42.3 dB is experimentally demonstrated in single wavelength operation with a booster EDFA. 32.2 dB of optical budget is obtained in WDM operation, with 6 channels transmitted in the booster EDFA and HC-NANF. These results are compliant in terms of budget and sensitivities with the future mobile X-haul.

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