Full-Duplex In-band OOK-Downlink/OFDM-Uplink Transmitted over 40km of SSMF in RSOA-based Radio-over-Fiber system

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***Abstract*— We experimentally demonstrate a full-duplex OOK-Downlink/WiFi OFDM-Uplink RSOA-based radio-over-fiber system. Properly adjusting the OOK downlink modulation index leverages the modulation erasing in RSOA and enables in-band OFDM-UL transmission over 40 km of single mode fiber.**

I. INTRODUCTION

Long reach passive optical network (PON) is the key solution for the emerging demand of capacity between the central office (CO) to subscribers while keeping the cost low at the user end (UE) [1]. Recently, there has been also increasing interest in small area access network where the CO receives analog wireless signals directly from remote antenna unit (RAU), and thus, power consumption is transferred to the CO where it is well managed [2].

Many radio-over-fiber systems based on reflective semiconductor optical amplifier (RSOA) have been intensively investigated to realize self-seeding, complete passive wavelength division multiplexing (WDM) PON or colorless point-to-point systems [3-6]. In these systems, saturated RSOA is employed to erase the amplitude modulation of the downlink (DL) stream and reflect back the carrier that is then re-modulated by directly driving the RSOA with an uplink (UL) signal. However, the modulation erasing in RSOA is imperfect and mainly limits system performance. Phase modulated DL signal is a more logical choice to avoid the erasing problem [3]. Another solution is to assign different spectral locations or overlapped channels for UL and DL streams [4]. These schemes, which require sophisticated receivers for DL signals, are not very practical for interfacing the CO with RAU where power-hungry RF front-end is not favorable. Other schemes have been proposed to support DL/UL analog wireless signals, but the drawbacks of either using different spectral bands or employing 2 transmission fibers still remain [5-6].

In this paper, we propose an effective technique to allow the transmission of an OOK-DL signal with WiFi OFDM-UL in a simple architecture that can be scaled easily to fit in a long reach CO-UE WDM-PON system or a CO-RAU access network. Experimental results are obtained as proof-of-concept and demonstrate the full-duplex transmission of 1Gb/s OOK-DL and 10MHz WiFi OFDM-UL at an intermediate frequency (IF) of 30MHz. Bit error rate (BER) below forward-error-correction (FEC) threshold is achieved for 64QAM mode at 40km of fiber whereas 16QAM and QPSK can be transmitted up to 70km and 80km respectively.

II. EXPERIMENTAL SETUP

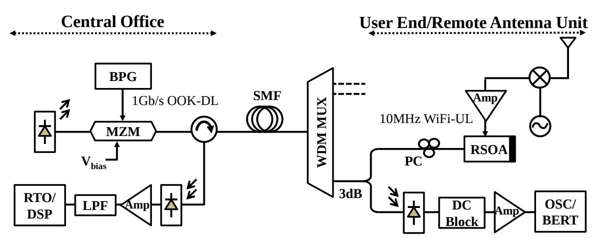

Fig.1. Experimental setup of self-seeding full-duplex OOK-DL and WiFi-OFDM-UL transmission.

Fig. 1 shows the experimental setup of the interface between CO and UE or RAU. The 1Gb/s OOK-DL signal is generated by sending a continuous wave (CW) to a Mach-Zehnder modulator (MZM) driven by a PRBS 2^{31}-1 electrical signal output from the bit pattern generator (BPG). An optical circulator at the CO is utilized to properly separate and direct the DL and UL streams. The OOK-DL signal propagates through the fiber and passes the WDM-multiplexer/demultiplexer before arriving at the UE/RAU. The signal is separated by a 3dB splitter, one arm goes to the RSOA (SOA-R-OEC-1550 from CIP) while the other goes to the photo-receiver for detection and evaluation by a sampling scope and a BER tester. The signal going to the saturated RSOA experiences modulation erasing due to gain compression. The reflected optical carrier is amplified by the RSOA and is modulated by the analog wireless signal applied directly to the RSOA. The wireless signal is generated by a vector signal generator (VSG) which simulates the wireless signal received by an antenna. Since the maximum bandwidth of the RSOA is limited to 1.2GHz, the WiFi signal is down-converted to an IF of 30MHz which is inside the OOK-DL bandwidth. This WiFi-OFDM-UL signal is then transmitted through the same fiber to the CO, directed by the circulator and received by the photo-receiver. The UL signal is then acquired by a 100MSa/s real-time scope and passed to digital signal processing (DSP). The OFDM frame structure is compliant with the WiFi 802.11a standard. The DSP flow is as follows: base-band down-conversion, re-sampling, frame-synchronization, frequency offset removing, preamble-based channel estimation, frequency domain equalization, demodulation, and detection.

To overcome the imperfect modulation erasing of OOK-DL by the RSOA, the modulation index of the OOK signal is appropriately adjusted. The modulation index can be minimized to keep the OOK-DL error free while erasure at the RSOA is optimized. Therefore, the interference to the UL signal is highly suppressed, allowing the transmission of an analog OFDM signal.

III. RESULTS AND DISCUSSION

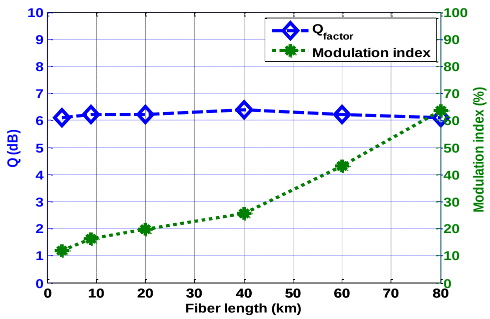

Fig. 2. Modulation index of the OOK-DL for error-free performance.

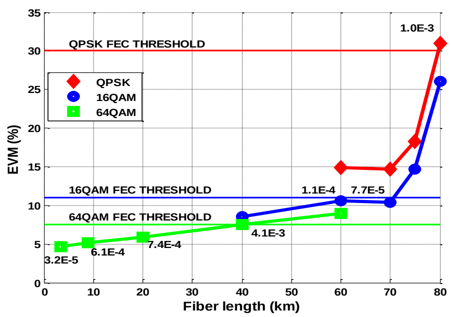

Fig.3. EVM /BER of WiFi OFDM-UL signal in different modes.

Fig. 2 shows the OOK-DL modulation index at the transmitter and its Q-factor at the receiver when changing the transmission fiber length. The modulation index is adjusted in each case so that the Q-factor remains above 6dB, ensuring BER below 10^{-9}.

The measured error-vector-magnitude (EVM) and corresponding BER versus fiber length for the OFDM-UL signal with QPSK, 16QAM, and 64QAM modulation modes are depicted in fig. 3. The EVM floors in each modulation mode are due to the residual amplitude modulation of the OOK-DL on the reflected carrier. The performance of 16QAM and QPSK modes degrades quickly as fiber length increases because the received power reduces to the minimum acceptance of the photo-receiver. At FEC threshold (BER $\approx 3.10^{-3}$), the operational length for 64QAM, 16QAM and QPSK are 40km, 70km and 80km respectively.

IV. CONCLUSIONS

We have been demonstrated a RSOA-based full-duplex radio-over-fiber experiment that transmits OOK-DL and OFDM-UL signals simultaneously in the same fiber. By adjusting the modulation index of the OOK-DL signal to assist the modulation erasing in RSOA, WiFi-OFDM-UL signal, regardless of modulation mode, is transmitted successfully over 40 km while error-free performance for the OOK-DL signal is maintained.

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