

Ubiquitous Coverage Next Generation Access Networks Based on Fiber/FSO Convergence with OBI-free Heterodyne Detection

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Abstract—Challenges facing NGA networks are not only high speed, but also ubiquitous coverage. We propose and experimentally demonstrate a Fiber/FSO converged system to achieve this. With heterodyne detection, it can combat at least 5-dB loss fluctuation in FSO links and achieve OBI-free OFDM upstream transmission.

Keywords—fiber optics communications, free-space optical communication, heterodyne detection

I. INTRODUCTION

Apart from high data rate and ultra-low latency, ubiquitous access is a desiring feature of next generation access (NGA) networks, which implies more remote radio units (RRUs) are expected to be deployed. Fiber-optic links have been extensively used in 4G/LTE access networks and will continue to play an indispensable role. However, it is geographically challenging and cost-prohibitive to set up fiber links, especially in dense urban areas. Free space optics (FSO) is an alternative solution with the advantages of lower implementation cost, rapid deployment, and highly available bandwidth [1]. Thereby, as illustrated in Fig. 1, to enable a ubiquitous connection, NGA networks are supposed to combine the strengths of lightwave transmission via both optical fiber and free space.

Dense deployment of RRUs also implies that a point-to-multipoint (PTMP) architecture should be considered. Among various multiplexing techniques, orthogonal frequency division multiplexing (OFDM) is a promising candidate with high spectrum efficiency and ease of signal processing. It can achieve higher capacity than time division multiplexing (TDM) and is more cost-effective and scalable than wavelength division multiplexing (WDM). However, in the upstream transmission, when multiple users use the same wavelength as the optical carrier, the random wavelength fluctuations from free-running lasers will generate optical beating interference (OBI), which greatly degrades the signal quality. Several solutions have been proposed, such as out-of-band RF clipping tone, where interference noise is spread over the spectrum [2], and coherent detection scheme, which can completely eliminate the OBI term [3]. On the other hand, FSO suffers from high propagation loss and is sensitive to weather effects. Certain weather conditions, such as fog, will cause increase in the link loss [4] and thus undermine the reliability of FSO communication systems. The coherent receivers, which are of high sensitivity, can also remedy the high and weather-dependent loss in FSO links, making it more favorable in our proposed Fiber/FSO converged

scheme.

In this paper, we experimentally demonstrate an OFDM-based PTMP upstream transmission in a Fiber/FSO converged access network, where we employ heterodyne detection to improve receiving sensitivity of FSO links as well as achieve an OBI-free upstream transmission. Different from our previous work [5] based on coherent detection where centralized light sources are used, we equip every transmitter with a laser. This distributed scheme relaxes the power requirement of the optical carrier, making it more tolerable to nonlinearity incurred in fiber transmission. Two 1.6-GHz bandwidth 16-QAM OFDM signals from two RRUs are transmitted simultaneously through 25-km single mode fiber (SMF). No OBI is observed and the reliability of FSO links gets enhanced.

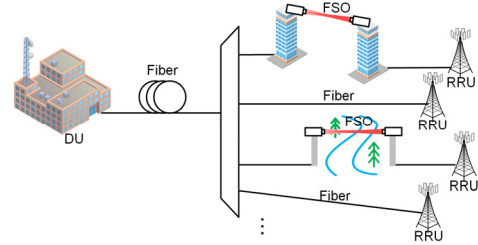


Fig. 1. Architecture of proposed ubiquitous NGA (DU: distributed unit).

II. EXPERIMENTAL SETUP AND RESULTS

The experimental setup is shown in Fig. 2. A system with two RRUs is demonstrated without loss of generality. High-performance lasers such as external cavity lasers (ECL) are required for heterodyne detection due to its susceptibility to phase noise. Because of the equipment restriction, one ECL (linewidth ≈ 10 KHz) and one distributed feedback (DFB) laser (linewidth ≈ 10 MHz) are used for the two RRUs, respectively. 16-QAM symbols are generated offline and loaded onto 1600 subcarriers. The FFT size is 8192 with subcarrier spacing of 2 MHz. Cyclic prefix (CP) length is set as 5.86% of FFT size. RF-pilot tones, which experience similar impairments with signals, are inserted to track carrier frequency offset (CFO) and phase noise. Power of RF-pilots and the gap between pilots and signals are to be optimized to achieve a balance between spectrum efficiency, nonlinearity and phase noise recovery. In this experiment, the pilot-signal gap is set as 100 MHz. It is worth mentioning that although the intermediate frequency (IF) generated by the beating between the optical carriers and LO also suffers from phase distortions, it cannot be used to estimate phase noise in the PTMP transmission. It is owing to the fact that

the received IF contains phase noise from multiple RRUs. Using it to revert phase noise of one RRU will only pollute the received OFDM signals. However, IF can play the same role as RF-pilot in the point-to-point (P2P) scheme.

After digital-to-analog conversion (DAC) and electrical amplification, baseband OFDM signals for RRU1 and RRU2 are fed to the corresponding MZM, which are both biased at the null point. To evaluate the Fiber/FSO convergence performance, signals from RRU1 also go through a one-meter FSO link before entering the fiber. Upstream signals of RRU1 and RRU2 are combined through a 3-dB coupler. Polarization controllers (PC) are inserted for both links before the coupler for polarization alignment, for the purpose of independent demodulation.

At the DU site, optical signals are amplified by an erbium-doped fiber amplifier (EDFA), and then filtered by a band-pass filter (BPF). Another ECL working at high power is used as local oscillator (LO). The received signal is free of corruption from OBI, as can be seen in Fig. 2(g). The residual interference noise in the baseband is due to the imperfections of optical hybrid and balanced photodetector (BPD). After coherent detection, a digital sampling oscilloscope is used to sample and digitize the signal. Offline digital signal processing (DSP) is later applied in Matlab to carry out down-conversion, down-sampling, synchronization, CFO recovery, carrier phase noise recovery, FFT, frequency domain equalization and QAM demodulation.

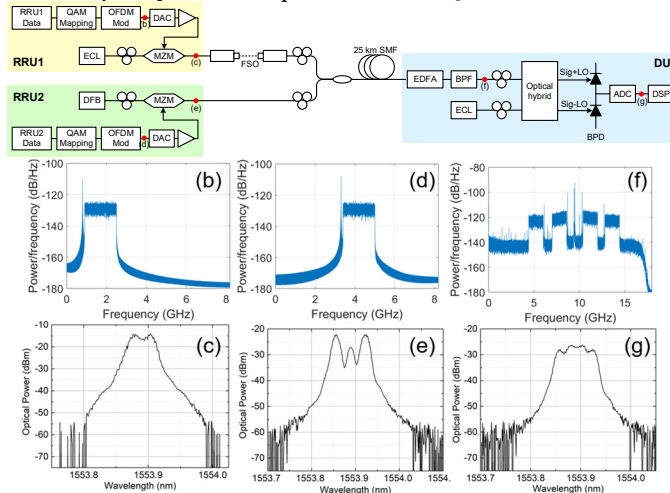


Fig. 2. (a) Experimental setup; (b)-(e) optical or electric spectra at corresponding points.

The measured bit error rate (BER) test results versus received optical power (ROP) for both back-to-back (B2B) and 25-km SMF transmission of RRU1 is drawn in Fig. 3(a). The case of only RRU1 transmitting data is shown as the benchmark. The LO power is 13 dBm. 25-km SMF leads to about 1 dB power penalty, mainly due to chromatic dispersion. And the penalty of introducing RRU2 is about 3 dB, since the SNR of RRU1 is reduced by 3 dB. Fig. 3(b) shows the BER results for RRU2, which exhibits similar behaviors as RRU1, but with worse performance. This difference originates from the DFB laser used for RRU2, which has larger linewidth than the ECL for RRU1 and its phase noise changes more rapidly. The receiver sensitivities at BER of 3.8×10^{-3} are -27.3 dBm and -23.6 dBm for RRU1 and RRU2, respectively. Fig. 3(d) and (e) shows the constellation diagram of RRU1 and RRU2 when they are transmitted together over 25-km SMF with ROP of -20.10 dBm.

Noise in constellation diagram mainly comes from residual phase noise and the nonlinearity in electrical amplification and photodetection. BPD used here has limited linear region and it induces distortion to the received OFDM signals as they have high peak-to-average-power ratio (PAPR). It can be partly solved by using DFT-spread OFDM or some machine learning techniques [6]. Fig. 3(c) represents the case when the loss of FSO link increases from 5 dB to 10 dB, signal degradation can be compensated by increasing LO power. Thereby, by adjusting the LO power at DU site, we can improve the system's vulnerability towards sudden changes in channels.

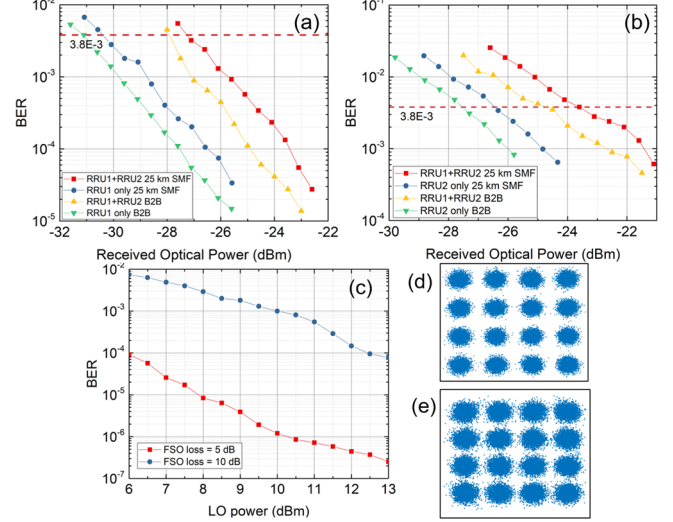


Fig. 3. Experimental results: BER versus ROP for (a) RRU1 and (b) RRU2; (c) BER versus LO power when the loss of FSO link is 5 dB and 10 dB; constellation diagram for (d) RRU1 (EVM=10.54%) and (e) RRU2 (EVM=13.35%).

III. CONCLUSION

We have proposed and demonstrated a Fiber/FSO converged access system for ubiquitous coverage NGA networks. By applying heterodyne detection at the DU side, it can remedy the transmission loss of FSO links and tolerate at least 5-dB loss fluctuation, at the same time eliminating OBI in OFDM uplinks. Our experimental results verify the feasibility of the proposed system by transmitting and decoding signals from two RRUs simultaneously, exhibiting improved sensitivity and reliability.

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