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High-Speed Wireless Access in Forested Rural Areas Using Analog Radio-over-Fiber Technology

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Abstract: A low complexity Ka-band hybrid photonic-wireless link based on a commercial SFP+ module is demonstrated, offering an economical and efficient solution for access provisioning to rural areas. A rain forest environment is emulated and low BER is achieved.

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1. Introduction

High speed communications access with optical fibers is a major challenge to some rural areas. Physical obstacles such as mountains and forests render fiber deployment either prohibitively expensive or impossible. Thus, a dynamic way to achieve these connections is by employing versatile photonic-wireless links operating in the lightly licensed millimeter wave (mm-wave) bands allowing transmission of large bandwidth signals. A leading method for the mm-wave generation is based on radio-over-fiber (RoF) links, providing wireless access to base stations over long distances.

A Ka-band RoF link is demonstrated based on incoherent heterodyne photonic upconversion supported by two independent light sources [1]. The optical signal modulation is provided by a commercial small form-factor pluggable (SFP+) module increasing the cost efficiency of the setup [2]. Indoor transmission is achieved at 2.5 Gbit/s for different RF frequencies (f_{RF}) with low bit-error rates (BER$<10^{-6}$). Humidified obstacles are put in the path of the wireless link, replicating a rain forest environment, and the impact on BER is examined.

2. Experimental Setup

As depicted in Fig. 1, a pulse pattern generator (PPG) is connected to a commercial SFP+ module emitting at f_s. The module provides a 2.5 Gbit/s non-return-to-zero (NRZ) signal based on a pseudo-random bit sequence (PRBS15) that has a length equal to 2^{15}-1 bits. In addition, an external cavity laser at f_{LO} is employed acting as a tunable local oscillator (LO). The frequency distance between the two tones is equal to the desired RF frequency ($f_s - f_{LO} = f_{RF}$).

The two optical signals are transmitted through a 10 km single mode fiber (SMF). The heterodyne photonic up-conversion is realized on a photodiode (PD), with an input optical power P_{OP} that is controlled by a variable optical attenuator (VOA). The amplitude of the generated RF current is directly proportional to P_{OP} and depends on the responsivity of the PD. The RF signal is amplified by a medium power amplifier (MPA) providing a gain of 30 dB before being transmitted over a 2 m wireless link, for which a pair of horn antennas with a gain of 18 dBi each is used.

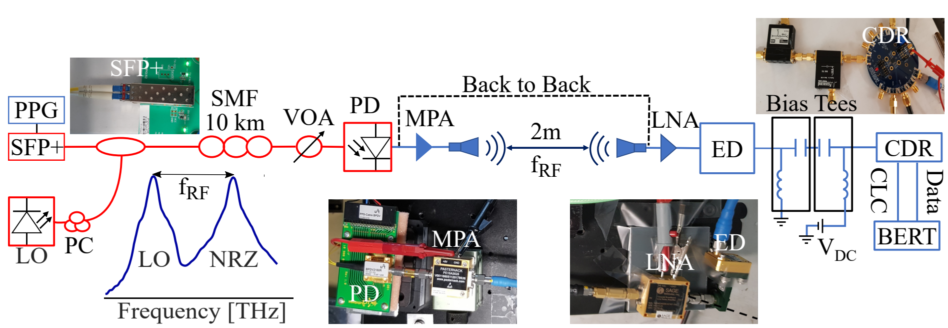

Fig. 1. The hybrid photonic-wireless link including the spectrum of the two optical tones.

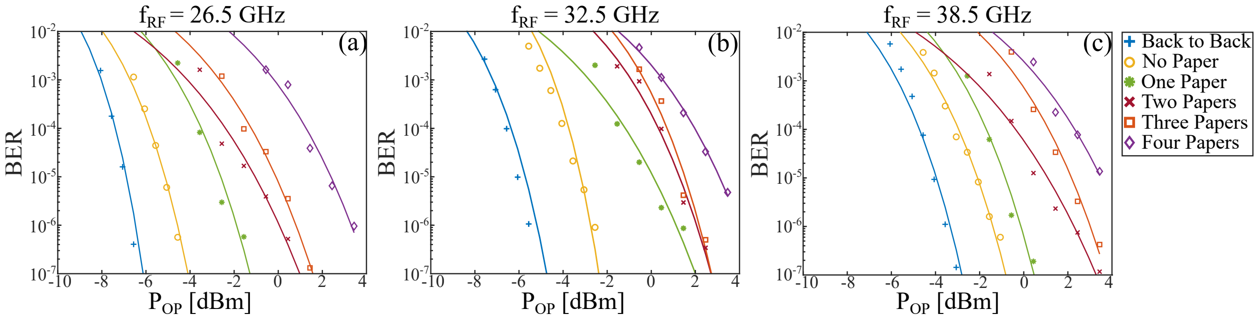

Fig. 2. Three figures of BER vs. Optical Power (P_{OP}) at the PD for three different RF frequencies (f_{RF}) within Ka-band for back to back, LoS and transmission with obstacles.

At the receiver, a low noise amplifier (LNA) boosts the RF signal by 40 dB and an envelope detector (ED) down-converts it to baseband. The baseband signal goes through two bias tees which remove the DC components and add another DC component (V_{DC}) compatible with the operation voltage of the clock data recovery module (CDR). The CDR extracts both the data and the clock (CLC) of the signal and the BER is recorded by the bit-error rate tester (BERT). This photonic-wireless link is characterized by low complexity in both the optical and RF domain while, the total cost is minimized since for the optical signal generation a commercial SFP+ module is used.

3. Experimental Results

Hybrid optical-wireless transmission is achieved over 10 km of optical fiber and a 2 m wireless link. Three different RF frequencies (26.5 GHz, 32.5 GHz and 38.5 GHz) are tested across Ka-band. For each frequency, 6 sets of measurements take place. The back to back connection is tested by attaching the output of the PD to the LNA and the BER is measured while the P_{OP} is increased. Then, the complete wireless link is assesed with line of sight (LoS) between the antennas. Finally, 4 measurement sets are conducted where highly humidified paper sheets (623.7 $cm^2/$ sheet) dipped into water are put in between the antennas. The wet paper sheets mainly consist of cellulose fibers from wood and calcium carbonate resembling the cellulose soft fiber structure of plant leaves. If it is assumed that the calcium carbonate embodied to the sheets does not add a significant attenuation, this process may give a rough estimate of the transmission quality of mm-wave signals that propagate through forest areas and plantations.

Figures 2(a), (b) and (c) show the BER as a function of P_{op} at the PD. Exponential fitting is used to model the measured data. Based on the back to back curve, the receiver's sensitivity for different BER values can be calculated by converting the P_{OP} into the electrical domain. In Fig. 2(a), the second curve to the right depicts the LoS wireless transmission measurement. By employing the wet sheets an additional layer of attenuation is added to the RF signal. Thus, in order to achieve the same BER levels, higher P_{op} are needed and therefore the BER curves are displaced to higher optical powers. Moreover, these 6 curves are further displaced (with a relatively small error offset) to the right in Fig. 2(b) and (c) due to the path losses that increase at higher frequencies.

4. Conclusions

An ARoF link based on an off-the-shelf SFP+ module is proposed. RF signals succesfully propagated through humid sheets that mimic tree leaves of a rain forest and low BER was obtained. The minimized complexity and cost-effective design of the total system will allow its implementation not only in remote rural areas, but also in tropical forests where fiber infrastructure deployment is impractical or deficient.

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References

[1] A. Morales *et al.*"Beam steering application for W-band data links with moving targets in 5G wireless networks," *J. Commun. Infor. Netw.* **2**, 91–100 (2017).

[2] S. Rommel *et al.*, "Outdoor W-Band Hybrid Photonic Wireless Link Based on an Optical SFP+ Module," *IEEE Photon. Technol. Lett.* **28**, 2303-2306 (2016).