

Remote Downconversion With Wavelength Reuse for the Radio/Fiber Uplink Connection

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Abstract—The authors present a novel technology for uplink transmission in radio-over-fiber distribution systems. The technique employs remote downconversion of the uplink data to intermediate frequency (IF) in the base station (BS). The local oscillator signal for the downconversion is optically generated in the central station (CS) and sent to the BS via optical fiber. The IF uplink data is then modulated onto an optical carrier, retrieved from the downlink signal, and sent to the CS, where the baseband conversion takes place. By employing this method of uplink connection, simplicity and cost efficiency of the BS is achieved.

Index Terms—Direct modulation, dispersion-caused fading, fiber Bragg grating (FBG), radio-over-fiber (RoF) systems, single sideband (SSB), uplink transmission.

I. INTRODUCTION

RADIO-OVER-FIBER (RoF) technology is a promising method of realizing high-speed access networks (solving the “last mile problem”) with an added benefit of mobility. It has been proposed that the future RoF systems would use millimeter-wave frequencies for data transmission in order to escape the spectral congestion. However, high atmospheric attenuation in this part of the radio spectrum would require a reduction in the size of the system cell. As a consequence, many base stations (BSs) would be necessary to cover the operational area of a system. Minimization of the BS cost is, therefore, a vital condition that has to be fulfilled for the successful deployment of such an RoF system. The architecture of the system and the method of realizing the uplink and downlink transmission have a large influence on the final cost of the BS (from a system perspective). In the case of downlink transmission, a remote generation of the radio-frequency (RF) carrier has been widely agreed upon. This has the advantage of concentrating the most expensive equipment in the central station (CS) and sharing this equipment between many BSs. There has been a lot of research activity in this area and some of the proposed methods of optical RF generation are direct and external modulation, heterodyning, mode-locking of a laser, and remote upconversion using the phototransistors, etc. [1]–[4].

Realization of the uplink, on the other hand, is more challenging. In this case, the high-frequency radio signal carrying data from the end station (ES) has to be encoded in the BS onto an optical carrier and then transmitted over the fiber to the CS. This places a requirement for high-speed components in the BS, which acts as a hindrance in achieving a low cost BS.

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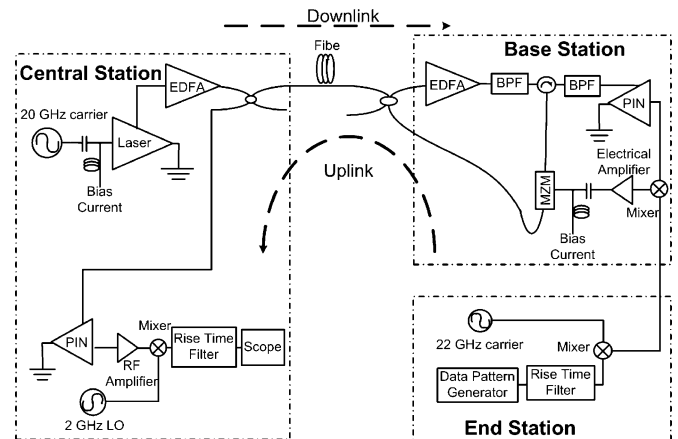


Fig. 1. Experimental setup.

Different methods have been proposed in order to solve the uplink problem. Many of them involve reusing the optical carrier from the downlink. Such an approach alleviates the necessity for a light source in the BS [3]–[6]. Nevertheless, the problem of high-frequency signals transmission between the BS and the CS (the need for high-speed components in the BS, dispersion-caused fading) remains unsolved. In this letter, we propose a simple uplink configuration by reducing the amount of high-speed components at the BS. We achieve this by transmitting an unmodulated RF carrier from the CS to the BS, where it is detected and used to downconvert the uplink data to an intermediate frequency (IF) [it acts as a local oscillator (LO)] [4]. In addition, the need for a light source at the BS is also omitted by reflecting part of the downlink optical carrier and modulating it, using a Mach–Zehnder modulator (MZM), with the IF uplink data. The output of the MZM is transmitted through the fiber to the CS, where the baseband conversion of the data is performed. Even though in this letter we concentrate on the uplink transmission, it should be noted that the LO could be combined with the downlink data signal, by employing subcarrier modulation (SCM) and retrieved from the detected signal with the use of an electrical splitter and an RF filter.

II. EXPERIMENTAL SETUP AND RESULTS

The architecture of the proposed RoF system is schematically shown in Fig. 1. The CS of our system consisted of a directly modulated high-speed laser, which had a threshold current of 10 mA and a modulation bandwidth of 26 GHz (at bias of 40 mA). The laser was modulated with a 20-GHz carrier, subsequent to which the output was amplified using an erbium-doped fiber amplifier (EDFA) and launched into 12 km of standard

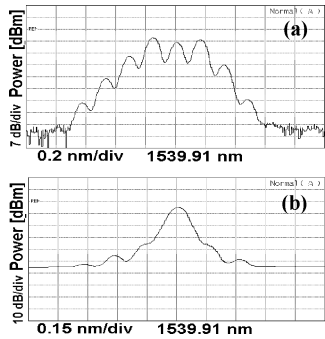


Fig. 2. Optical spectrum: (a) downlink, (b) uplink.

single-mode fiber. The optical power at the input of the fiber was measured to be 4 dBm.

At the BS, the optical signal was amplified once again and filtered using a fiber Bragg grating (FBG). This amplification was necessary due to high insertion loss of the single sideband (SSB) filter (7 dB) and the low responsivity of the photodiode used for uplink signal detection. If these limitations were overcome, the EDFA at the BS would not be necessary. The FBG placed in the BS fulfils two tasks: first, it may act as a demultiplexer in a wavelength-division-multiplexing RoF system. Second, it converts the incoming double sideband (DSB) signal to the SSB format (avoids dispersion-caused fading of the RF signal). Part of the optical carrier was then reflected using a very narrow-band FBG (3-dB bandwidth of 0.08 nm and 60% reflectivity) in conjunction with an optical circulator. The rest of the signal [see Fig. 2(a)] was detected using a high-speed photodiode (optical power falling on the detector was 1.6 dBm) in order to retrieve the 20-GHz signal sent from CS, which was then used to downconvert the data from the ES. The uplink data was a 150-Mb/s pseudorandom bit sequence, generated by an Anritsu pulse pattern generator, upconverted to 22 GHz. In reality, a high-speed electrical amplifier would be required after the receiving antenna in order to boost the power of the incoming signal (we did not use the amplifier since there was no physical radio link in our setup).

After mixing the uplink signal with the LO, the resulting IF data signal (on a 2-GHz carrier) was intensified using an electrical amplifier and used to externally modulate the reflected optical carrier. The output of the MZM was then launched into the fiber and sent to the CS [see Fig. 2(b)]. In order to verify the influence of the propagation of the downlink and uplink signals on the same wavelength and over the same fiber, two system configurations were used. First, the downlink signal was sent using Fiber 1 and uplink using Fiber 2. Second, both signals were sent over the same fiber (Fiber 1). At the CS, the uplink signal was detected using a low-speed (3 GHz) photodiode. After electrical amplification, the uplink data was downconverted to baseband using a mixer and a 2-GHz signal from an LO. After filtering out the undesired components, the data was displayed using an oscilloscope in order to verify the quality of the signal.

The measured BER versus received optical power is shown in Fig. 3. The performance of the system was verified for three different system configurations: 1) back-to-back [no fiber transmission (diamonds)], 2) two separate fiber reels for uplink and downlink signals (squares), and 3) both signals sent over the

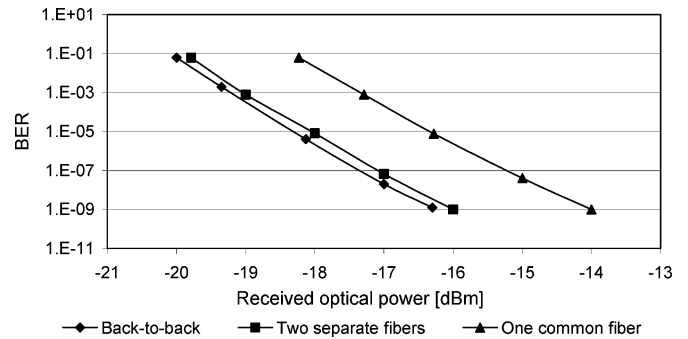


Fig. 3. BER versus received optical power.

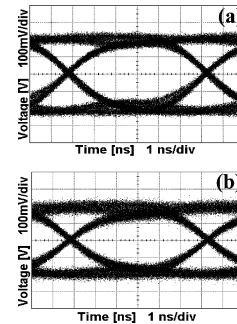


Fig. 4. (a) Eye diagram for back-to-back case; (b) eye diagram for system with single-fiber reel optical (power falling on the detector -8.8 dBm).

same fiber (triangles). It can be seen that there is less than 0.5-dB power penalty between Cases 1 and 2 (at BER of 10^{-9}). Transmitting the uplink and downlink signal over the same fiber degrades the system performance by a further 2 dB. This could be caused by the nonlinear fiber effects or the interference from the downlink signal through the BS coupler. The eye diagrams for Cases 1 and 3 with a power of -8.8 dBm falling on the detector are shown in Fig. 4(a) and (b), respectively.

III. CONCLUSION

The results presented above prove that remote downconversion with wavelength reuse is a feasible technique that could be used for the realization of the uplink connection in an RoF system. Downconversion of the uplink data to IF at the BS eliminates the requirement for high-speed external modulators or high-speed laser diodes that might be necessary if other architectures are implemented [4], [6]. The IF modulation also allows the transmission of many RF channels simultaneously using the same light source (using SCM) as well as the transmission of a DSB signal without it being exposed to dispersion-caused fading. Therefore, we do not need any optical filtration to convert the signal to SSB format. This not only reduces the amount of hardware required but also doubles the optical power available for transmission (in comparison to SSB format).

The need for a light source at the BS is avoided by reusing the optical carrier from the downlink as proposed in [4]–[6]. Nevertheless, because we transmit the uplink and downlink signals using different RF frequency, our method allows the simultaneous transmission of the signals in both directions using the same wavelength and fiber (RF modulated carrier for downlink and IF modulated for uplink). This increases the spectral efficiency of the system by up to 100% in comparison with a system

that needs to use separate wavelengths for the transmission of uplink and downlink signals.

REFERENCES

- [1] T. Kuri *et al.*, "Fiber-optic millimeter-wave downlink system using 60 GHz-band external modulator," *J. Lightw. Technol.*, vol. 17, no. 5, pp. 799–806, May 1999.
- [2] G. J. Simonis *et al.*, "Optical generation, distribution and control of microwaves using laser heterodyne," *IEEE Trans. Microw. Theory Tech.*, vol. 38, no. 5, pp. 667–669, May 1990.
- [3] A. J. Vieira *et al.*, "A mode-locked microchip laser optical transmitter for fiber radio," *IEEE Trans. Microw. Theory Tech.*, pt. 2, vol. 49, no. 10, pp. 1882–1887, Oct. 2001.
- [4] H. Sawada *et al.*, "An experimental study on a self-oscillating up-converter that uses a heterojunction bipolar transistor," *IEEE Trans. Microw. Theory Tech.*, vol. 47, no. 8, pp. 1515–1521, Aug. 1999.
- [5] T. Kuri *et al.*, "A single light-source configuration for full-duplex 60-GHz-band radio-on-fiber system," *IEEE Trans. Microw. Theory Tech.*, vol. 51, no. 2, pp. 431–439, Feb. 2003.
- [6] A. Nirmalathas *et al.*, "Wavelength reuse in the WDM optical interface of a millimeter-wave fiber-wireless antenna base station," *IEEE Trans. Microw. Theory Tech.*, pt. 2, vol. 49, no. 10, pp. 2006–2012, Oct. 2001.