Remote Downconversion Scheme for Uplink Configuration in Radio/Fiber Systems

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ABSTRACT
The authors present a novel technology for uplink transmission in Radio over Fiber (RoF) distribution systems. The technique employs remote downconversion of the uplink data to Intermediate Frequency (IF) in the Base Station (BS). The Local Oscillator (LO) 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 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.
Keywords: Radio over Fiber systems, uplink transmission, direct modulation, dispersion caused fading.

1. 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 a RoF system. The architecture of the system and the method of realizing the up- 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 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, 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.

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. Kuri *et al.* in [5] combine the downlink data signal with an unmodulated RF carrier at the CS and use it to externally modulate an optical carrier. At the BS the optical signal is split and part of it detected in order to recover the downlink signal, which is then transmitted to an ES using the microwave antenna. The rest of the signal is externally modulated with the signal received from the ES, converted to Single SideBand (SSB) format using an optical Band Pass Filter (BPF) and transmitted over the fiber back to the CS. In the CS the uplink data is optically downconverted (by mixing the unmodulated RF carrier with the uplink signal in the photodiode). In another report by Bakaul *et al.* [6]external modulation at the BS is also used. In experiments described in [6] the optical carrier generated in the CS is externally modulated with the downlink signal and transmitted to the BS. There the optical carrier is partially reflected by a narrow band FBG with 50 % reflectivity and then reused - modulated using a dual-drive MZM with the uplink signal. This method of external modulation produces a SSB signal, therefore no optical filtering in the BS is necessary in order to avoid dispersion caused fading. Yet another method, which uses the optical carrier generated at the CS, is proposed by Hu *et al.* [7]. In this case the RF carrier is generated by the heterodyning of two optical modes generated by a Mode Locked Laser (MLL). There is a separate pair of optical carriers for up- and downlink transmission. At the BS the two modes designated for the uplink are externally modulated with the signal from the ES. In this case also no SSB filtering is required since at the CS the uplink data is downconverted in an optical manner to an IF.

All the above-described methods require a high-speed external modulator at the BS. This is a major drawback, since a high-speed external modulator is an expensive device. The requirement for an optical source in the BS is omitted by reusing the optical carrier sent from CS. Most of these techniques, apart form [7], would require the use of an EDFA due to splitting the optical carrier between the down- and uplink. Another disadvantage of the above-described approach is a need for SSB conversion in order to avoid the dispersion caused fading. This results from transmitting the uplink data to CS without downconverting it. The SSB conversion is achieved by either optical filtering or utilization of dual-drive external modulator, which obviously increases the complexity of the BS. Finally, reusing the optical carrier strictly limits the network topology that can be implemented for RoF system. When the same wavelength is used for up- and downlink the two signals have to be transmitted over a separate fiber in order to avoid the interference between up- and downlink. If only one fiber is available the system can only employ ring architecture.

In this paper we propose a cheaper 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 BS, where it is detected and used to downconvert the uplink data to an Intermediate Frequency (IF) (it acts as a Local Oscillator - LO). The IF uplink data is then used to directly modulate a low-speed laser diode. The output of this laser is transmitted through the fiber to the CS, where the baseband conversion of the data is performed. Although in this paper we concentrate on the uplink transmission, it should be noted that the LO could be combined with the downlink data signal, by employing SCM and retrieved from the detected signal with a use of an electrical splitter and a RF filter. The remote downconversion of the uplink signal was also proposed by Lim et al.[8]. The main difference between the experiments described in [8] is that in our system the downlink data is upconverted to RF at the CS and the LO transmission is designated only for the uplink downconversion. The method of LO generation is also different and more efficient in terms of power and spectrum occupation. Finally, the uplink data is downconverted to IF frequency not baseband, which allows downconversion and transmission of multiple RF channels simultaneously.

2. EXPERIMENTAL SET-UP

The basic architecture of our system is shown in Fig. 1. The CS of our systems consists of a directly modulated high-speed NEL laser. The diode has a threshold current of 10 mA and a modulation bandwidth of 26 GHz. The laser is modulated with the 20 GHz carrier. The output of the transmitter (see Fig. 2a) is then amplified using EDFA and launched into 12 km of Standard Single Mode Fiber (SSMF). The optical power at the input of the fiber is 4 dBm.

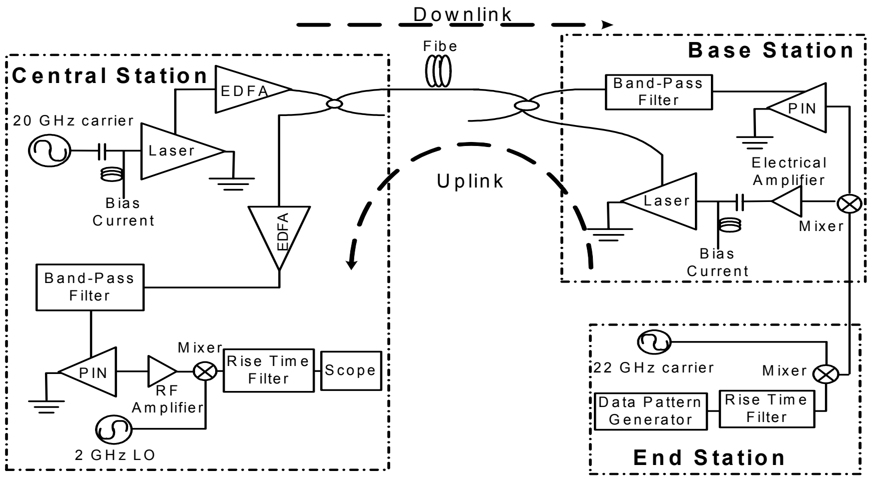

Figure 1. System architecture.

At the BS the optical signal is filtered using a Fiber Bragg Grating (FBG). The FBG fulfils two tasks: firstly, it may act as a demultiplexer in the WDM system [9]. Secondly, it converts the incoming Double Side Band (DSB) signal to SSB format (to avoid the dispersion caused fading of the RF signal) (see Fig. 2b).

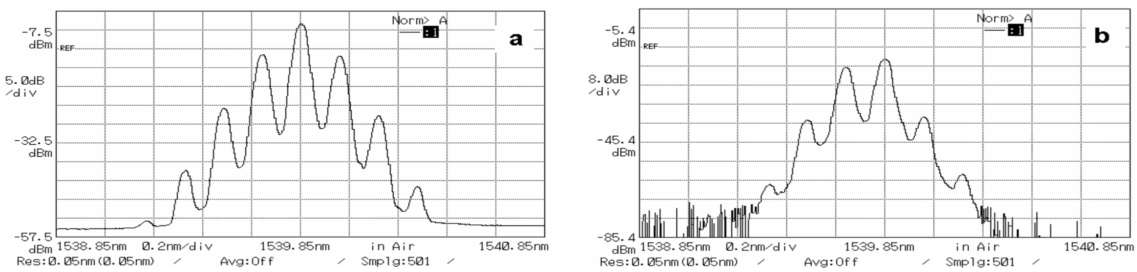

Figure 2. Optical spectrum of the downlink signal: (a) DSB, (b) SSB format.

The 20 GHz signal sent from CS is then detected using high-speed photodiode and used to downconvert the data from the ES (optical power falling an the detector was –2.3 dBm). The uplink data used is a 140 Mb/s Pseudo Random Bit Sequence (PRBS) from an Anritsu Pulse Pattern Generator (PPG), upconverted to 22 GHz (see Fig. 3). 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 set-up).

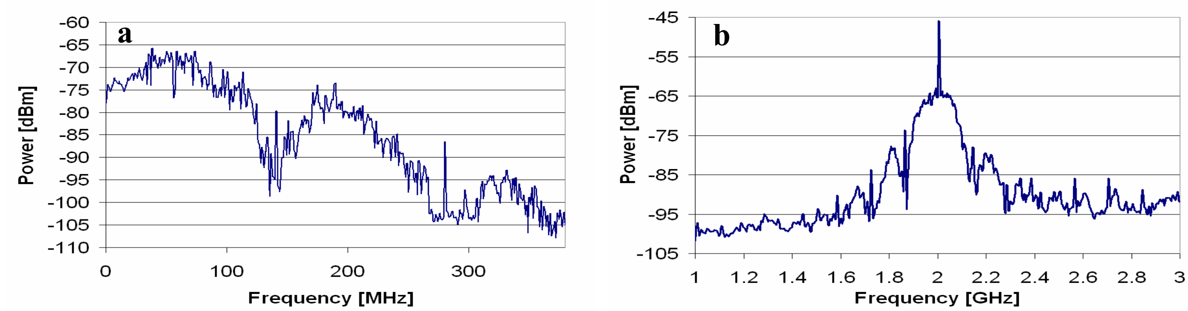

Figure 3. Electrical spectrum of the (a) data signal, (b) data upconverted to 22 GHz.

After mixing the uplink signal with the LO the resulting IF data signal (on 2 GHz carrier see Fig. 4a) is amplified and used to directly modulate a laser diode. The laser is a low-speed device designed for 2.5 Gb/s transmission. The output of the diode is then launched into the fiber and sent to the CS. The optical spectrum of the uplink signal is shown in Fig. 4 b. The two side bands visible in the optical spectrum are generated by the undesired high frequency components that are present at the output of the mixer as shown in Fig. 4c (20 GHz carrier, 22 GHz original uplink data).

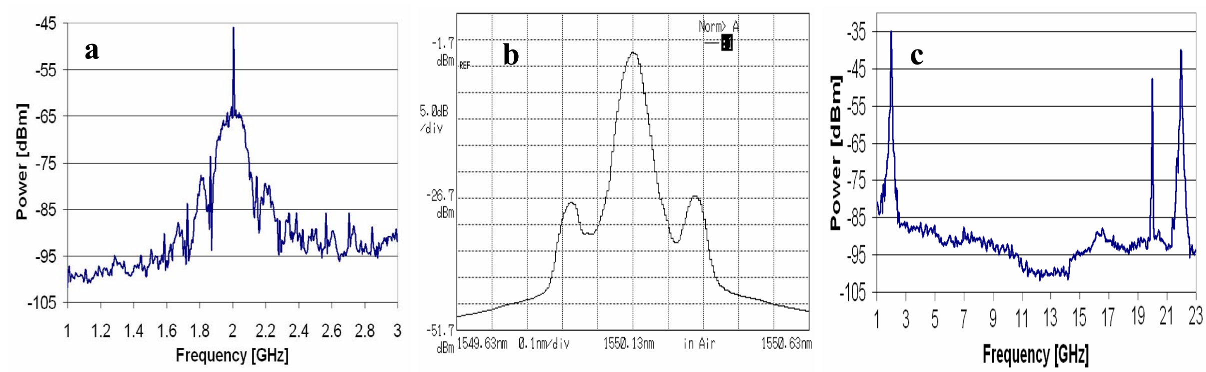

Figure 4. (a) Optical spectrum of the uplink signal, electrical spectrum of the (a) modulating signal (after the BS mixer), (b) IF data signal.

At the CS the signal is optically amplified, filtered out (to avoid any interference from the reflected downlink signal) and detected using a low-speed (3 GHz) photodiode. After electrical amplification the uplink data is downconverted to baseband using a mixer and the 2 GHz signal from the LO. After filtering out the undesired components the data is displayed using an oscilloscope and BER is measured using an Anritsu Error Detector .

The measured BER vs. received optical power is shown in Fig. 5a. The performance of the system was verified for three different system configurations: back-to-back (triangles), no fiber transmission for the IF uplink signal (diamonds) and the complete RoF system (squares). It can be seen that there is less than 1 dB power penalty between the back-to-back case and the complete system performance. This could be attributed to noise introduced by the fiber transmission. The received eye diagram for the complete system and the optical power falling on the detector of –10 dBm is shown in Fig. 5 b.

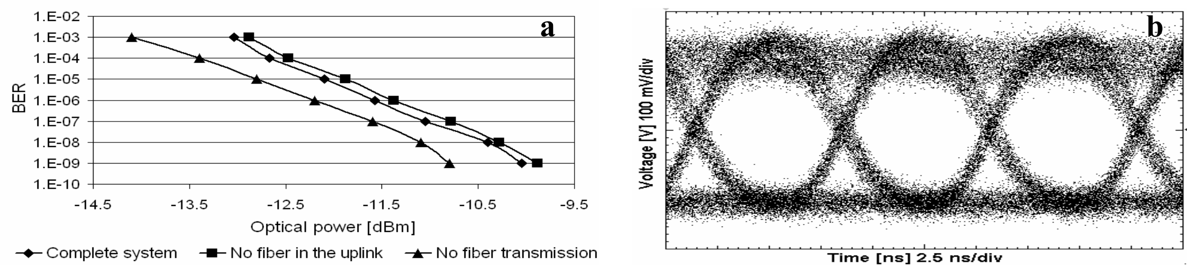

Figure 5. (a) BER vs. received optical power, (b) eye diagram of detected signal (complete system, received power –10 dBm).

3. CONCLUSIONS

The results presented above prove that remote downconversion is a feasible technique for the realisation of the uplink connection in RoF systems. By downconverting the uplink data to IF at the BS we avoid the need of high-speed external modulator or laser diodes that might be necessary if other architectures are implemented. The IF modulation also allows us to transmit many RF channels simultaneously using the same light source (using SubCarrier Modulation - SCM) as well as transmit 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 could be considered as a disadvantage, especially in situations when the BS might be exposed to severe climatic variations. In such cases the stability of the signal could be difficult to ensure (e.g. unacceptable wavelength drift). This could be avoided by reusing the optical carrier from the downlink as proposed in [2, 3]. By combining our method with the above-mentioned scenario one could be able to transmit the down- and uplink signals using the same wavelength and the same fiber (RF modulated carrier for downlink and IF modulated for uplink) [10]. This would increase the spectral efficiency of the system by up to 100% in comparison to a system that needs to use separate wavelengths for the transmission of the uplink and downlink signals.

ACKNOWLEDGEMENTS

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