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Prince, Kamau ; Chiuchiarelli, A; Presi, M; Tafur Monroy, Idelfonso ; Ciaramella, E

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All-Optical Delay Technique for Supporting Multiple Antennas in a Hybrid Optical - Wireless Transmission System

Kamau Prince (1), Andrea Chiuchiarelli (2), Marco Presi (2), I. Tafur Monroy (1) and Ernesto Ciaramella (2)
1 : DTU Fotonik, Tech. Univ. Denmark, Kgs. Lyngby, DK-2800 Denmark. kpri@fotonik.dtu.dk
2 : Scuola Superiore Sant'Anna, via Moruzzi 1, Pisa 56124, Italy. andrea.chiuchiarelli@cnit.it

Abstract

We introduce a novel continuously-variable optical delay technique to support beam-forming wireless communications systems using antenna arrays. We demonstrate delay with 64-QAM modulated signals at a rate of 15 Msymbol/sec with 2.5 GHz carrier frequency.

Introduction

Rapid increases in the coverage and speed of optical communications networks, combined with recent increases in the coverage and throughput of wireless access networks, has motivated a desire for increased data bandwidth delivery via the convergence of hybrid optical/wireless communications networks. This has motivated interest into the integration and transmission of radiofrequency (RF) signals over fiber optic infrastructure [1]. To increase the throughput of the air interface while maintaining high spectral efficiency, newer-generation wireless access networking schemes, including mobile WiMAX (based on IEEE 802.16e) and the latest draft of the wireless IEEE 802.11n LAN standard, will implement RF signal transmission supporting (and with 802.11n requiring) multiple transceiver antennas at either end of the wireless link. This allows increased data throughput by exploitation of statistical properties of the wireless channel response. Such arrayed-antenna schemes can support the steering of the wireless RF beam to maximize received energy at the remote transceiver, or implement simultaneous communication paths via multiple active antennas at each terminal.

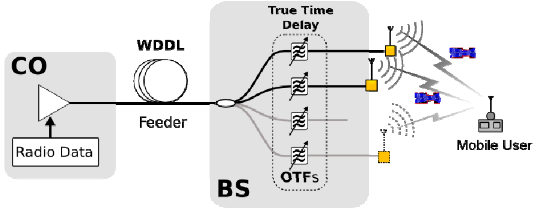

Figure 1: Proposed system concept: wideband optical source, wavelength-dependent delay line (WDDL) and Optical Tunable filter (OTF) achieve tunable all-optical delay. The resulting radio beam from the antenna array is steered towards the mobile user.

Previously, multiple-antenna radio over fiber delivery schemes typically utilized more complex schemes, implementing switched discrete optical delay [2] or multiple optical sources [3]. We propose an alternative converged ROF access scheme, which integrates native support for multiple access antennas, while retaining the other advantages of optical distribution systems [4]: our proposed system is shown on the left of Fig. 1. We demonstrate the achievement of all-optical true-time delay of a 2.5 GHz RF signal modulated reflecting SOA (RSOA), optical tunable filter (OTF) and wavelength-dependent delay line (WDDL) and report on successfully transmission, delay and recovery of the pore and modulated carrier wave. This protocol-independent scheme supports a wide variety of modulation formats and implements the delay required for full 2π beam steering of a 2.5 GHz radio wave, with appropriately spaced antennas. We obtained results indicating an unmodulated phase noise below -100 dBc at 1 kHz offset for the output carrier, and good results with 64 QAM modulation.

Experimental Setup

In this system, the message modulates a wideband optical signal which propagates through a wavelength-dependent delay line: optical filtering is done to select the desired differential time delay between radiating antennas and achieve beam-steering of the transmitted RF signal as presented in Figure 1. The experimental setup is shown in Fig. 2.

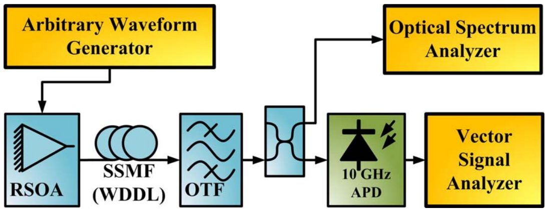

Figure 2: Experiment layout diagram.

The wideband amplified spontaneous emission (ASE) noise output of a RSOA is directly modulated by an RF signal with a 2.5 GHz carrier frequency. The RSOA was a commercial device, providing 22 dB small-signal gain and 0 dBm output saturation power when biased at 70 mA at 18 °C temperature. The ASE had 20 nm FWHM and provided -3 dBm total output power with a peak at approximately 1549 nm. The signal propagated through a WDDL implemented with 2.1 km standard SMF (17 ps/nm•km dispersion) and a 2 nm FWHM OTF: a 10 GHz APD was used at the receiver. The RF signal was generated with an

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Agilent E4438C ESG generator and evaluated with a 26.5 GHz Agilent N9020 MXA Signal Analyzer.

Results

Figure 3 reports the measurement of the true-time-delay (TTD) as a function of the filter detuning. We observe an exact linear relation over the whole filter bandwidth. The TTD is independent of OTF bandwidth. We assessed the noise performance of the system by evaluating phase noise at the system output (dashed, blue) for an unmodulated input: the results are reported in Fig. 4. The phase-noise of the input RF tone (solid, black) is also reported for comparison. These results indicate that the phase noise degradation through the system is below 20 dB. We additionally note that the output phase noise was less than -100 dBc/Hz at a 1 kHz offset.

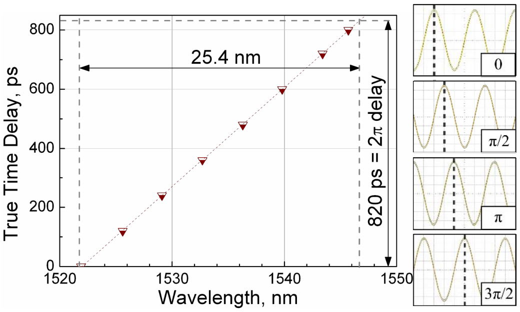

Figure 3: Showing delay vs. OTF central wavelength. Sample delayed RF waveforms (right) show low attenuation over delay range.

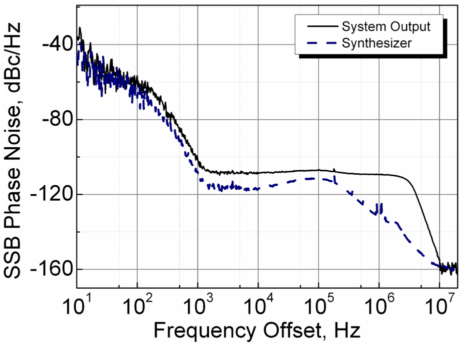

Figure 4: Single-sideband (SSB) phase noise variation with offset frequency, at input and output.

We then assessed system performance with 64-QAM modulation at a rate of 15 Msymbol/second (Msps) and an input RF power of +11 dBm: Fig. 5 shows the post photodetection RMS error vector magnitude (EVM) as a function of the wavelength detuning. Over the 26 nm detuning wavelength range of interest, we obtained EVM values below 2.5%, which is well below the 3.1% RMS EVM requirement for single-channel WiMAX transmissions using this modulation format. We anticipate that lower signaling rates would be associated with improved performance.

Figure 6(a) presents the post-detection constellation and Fig. 6(b) present the Q-symbol eye diagram. These show reliable symbol demodulation and the clear eye opening indicates good system transmission performance. The SNR penalty incurred by transmission through this system is approximately 11.5 dB, and enables us to place a bound on the SNR requirements at the input to this transmission to support WiMAX compliant communications.

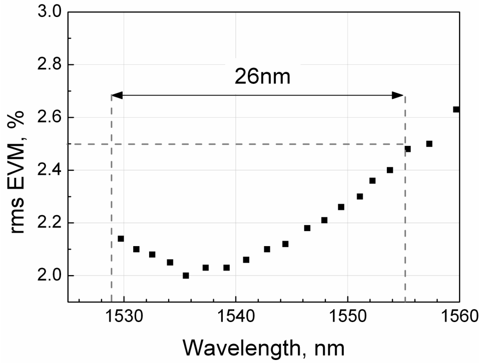

Figure 5: RMS EVM as a function of wavelength detuning for 64-QAM at 15 Msps (90Mbps). This EVM profile follows the inverted power profile of the RSOA. This OTF prevented testing below 1529 nm.

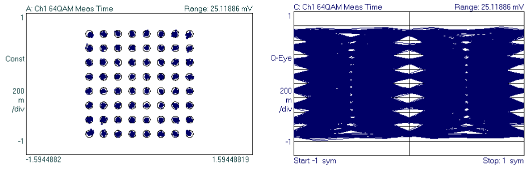

Figure 6: Output 64-QAM constellation (a, left) and Q symbol eye diagram (b, right).

Conclusions

We have successfully demonstrated radio over fiber transmission system implementing all-optical delay. We transmitted a 2.5 GHz RF signal modulated at 64 QAM over the system and obtained an RMS EVM of 2.5% at a signaling rate of 15 Msps (corresponding to 90 MBps). The system supports multiple-antenna schemes and is potentially compatible with a wide range of transmission schemes

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