Wide-Bandwidth, Enhanced-Quality Wireless Signal Detection with Low-Bandwidth Devices

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Abstract: We discuss a new method for detecting high-bandwidth wireless signals with low-bandwidth electronics. We experimentally demonstrate the detection of 24 GBd-QPSK Nyquist data with 4 GHz electronics and a Q-factor enhancement of 2.2 dB.

1. Introduction

Wireless communications as well as radar, lidar, sensing, and measurement applications have to deal with increasing bandwidths and enhanced demands for the measurement or detection quality [1, 2]. However, nonlinearity and jitter problems in high-speed electronic processors and especially in analog to digital converters (ADC) limit the maximum achievable bandwidth in state of the art electronics [3 -5]. The resolution, as given by the signal-to-noise and distortion ratio (SINAD) of an ADC for a given jitter value depends quadratically on the bandwidth of the electronics [6]. Thus, reducing the bandwidth of the signal will not only allow using lower bandwidth equipment for the detection, but at the same time, it will reduce the effect of the jitter and increases the resolution [4]. Lower bandwidth detectors and electronics drastically reduce the integration requirements and they might open the way to keep pace with further increasing data rates and bandwidths.

A bandwidth reduction of wireless signals can be achieved with the help of optics and integrated photonics. There are several optical methods for a bandwidth reduction of wireless signals. One of these solutions is spectrum slicing [7], where the high-bandwidth signal spectrum is sliced into low-bandwidth sub-signals which are then detected by parallel low-bandwidth coherent detectors. However, spectrum slicing has very high demands on the filter functions and the following post-processing of the signal. Another optical solution is based on stretching the high bandwidth signal in the time domain by time magnification methods, like a time magnifier, or a time lens [8, 9]. This time-stretched signal can be detected with low-bandwidth detectors. The electrical envelope of the signal can then be sampled and quantized with low-bandwidth ADC. However, the time-lens [8] requires a strong first order dispersion, which is quite hard to integrate. But, much more important is the fact, that first order dispersions are usually accompanied with higher order dispersion effects, which distort the signal.

Here we demonstrate a new method for the photonics assisted detection and measurement of high-bandwidth signals with low-bandwidth electronics, based on time-interleaved sinc-pulse sequences and frequency-time coherence sampling [4]. We will show the reception of a 24 GBd Nyquist shaped QPSK electrical signal (12 GHz baseband bandwidth) with 4 GHz electronics in three branches. As we will show, this method does not only reduce the bandwidth requirements on the electronics and digital signal processing, at the same time a 2.2 dB Q-factor performance enhancement was obtained experimentally by comparison with the direct detection of the signal.

2. Basic Concept

The basic principle for the detection and processing of a broad-bandwidth wireless/wired signal with low-bandwidth parallel branches by time-frequency coherence based time interleaving is shown in Fig.1. The wireless signal with the bandwidth Be is transferred to the optical domain by an antenna coupled to a modulator. To avoid the power division required for a single source, the modulator is driven with a number of p laser diodes (LD) of different wavelengths. A wavelength division demultiplexer is utilized to demultiplex the signal into p copies $s(t)$ at the different wavelengths. The bandwidth of the optical signal $s(t)$ for every single wavelength is $B = 2Be$. In each branch, the optical signal $s(t)$ is sampled by a sinc-pulse sequence with bandwidth B and a repetition rate of B/p at a proper phase shift. The generation of the sinc-pulse sequence with a number of frequency lines p and a bandwidth of $B= p\Delta f$, with Δf as the frequency spacing between the lines, together with the multiplication of the signal with this sequence is carried out simultaneously in the single modulator in the branch [10]. The modulator has to be driven with one or $n=(p-1)/2$ RF frequencies generated from an oscillator and the required time shift between the branches is assured by a phase shift of the RF frequencies of $\phi = 2\pi/p$ [11]. A coherent detector and an ADC of low-bandwidth $B/(2p) = Be/p$ are

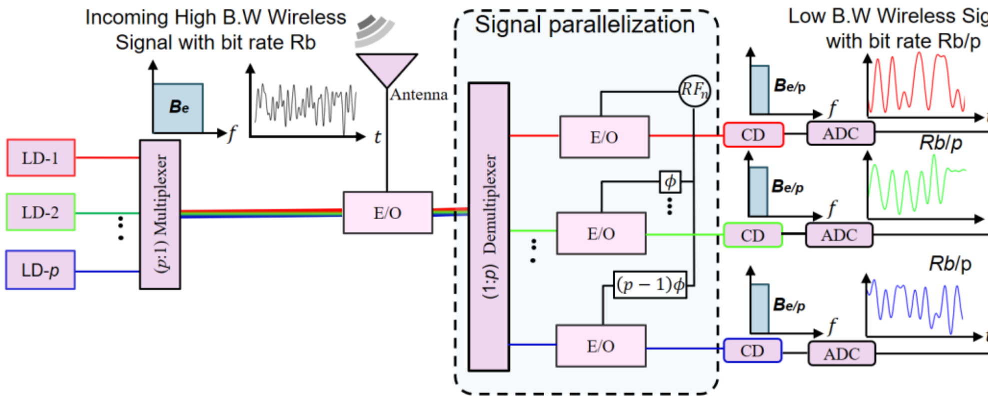

Fig. 1 Basic concept of the proposed method. The colored lines indicate the optical signals at different wavelengths, and the black lines represent the electrical signals. Please note that we have incorporated the p different LDs at different wavelengths only to avoid the power split. A single source with p times the power at one single wavelength will have the same effect. In this case the WDM demux has to be replaced with a 1:p power splitter. LD: laser diode, E/O: electro-optical modulator, CD: coherent detection, and ADC: analog to digital conversion.

accustomed to retrieve the information from the signal in each branch. The whole information of the high bandwidth signal can be retrieved after putting the information from all three branches together.

When only one single RF frequency Δf (n = 1) is used, the number of LDs at different wavelengths, that are corresponding to the number of required branches, will be $p = 2n+1 = 3$, and the electrical phases in the three branches have to be 0º, 120º, and 240º. Hence, the three branches together are necessary to detect the whole information of the broad-bandwidth signal. The required electrical bandwidth of the modulator for the sampling is just Δf and the whole real-time sampling rate from the three branches together is $3\Delta f$, enabling a sampling of wireless signals with the Nyquist bandwidth 1.5 Δf.

3. Experiment and Results

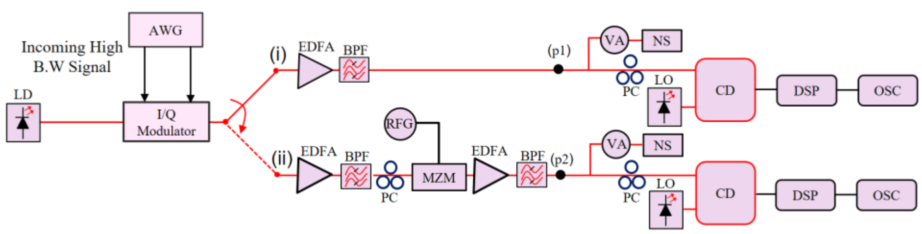

Fig. 2 Experimental setup for comparing the direct measurement (i), and the proposed method (ii). LD: laser diode, AWG: arbitrary waveform generator, EDFA: erbium-doped fiber amplifier, BPF: bandpass filter, PC: polarizer controller, MZM: Mach-Zehnder modulator, VA: variable attenuator, NS: noise source, LO: local oscillator, CD: coherent detector, DSP: digital signal processing, OSC: oscilloscope.

The schematic illustration of the experimental setup is shown in Fig. 2. The received high-bandwidth wireless signal after the antenna is formed with two arbitrary waveform generators (AWGs) of sampling rate 50 GS/s. They generate a 24 GBd QPSK electrical signal, limited to its Nyquist bandwidth of 12 GHz. A phase\quadrature (I/Q) modulator is employed to convert the signal into the optical domain at 1550 nm wavelength. For the direct measurement branch (i), the signal is directly measured with a coherent detector (CD) with a local oscillator (LO) followed by an ADC and digital signal processing (DSP). Detector and processing have a bandwidth of 12 GHz. For analyzing the noise performance of the setup, white noise of different amplitude is directly added to the signal before detection, to adjust the SNR of the received signal (NS and VA). The experimental setup for the proposed method is shown in branch (ii). It is basically the same, except of an additional MZM and an EDFA followed by a bandpass filter for reducing the amplified spontaneous emission noise of the EDFA. The 24 Gbd QPSK Nyquist signal is sampled with the simultaneously generated sinc-pulse sequence by the MZM driven with an 8 GHz RF frequency from a radio frequency generator (RFG). The other main difference to branch (i) is, that the electrical signal processing of the same coherent detector and signal processing system as in branch (i) is now reduced to a bandwidth of 4 GHz, i.e. 1/3rd of branch (i). The performance of the proposed method was compared with that of direct detection in terms of Q-factor measurements. For a fair comparison between the methods, the powers at points (p_1) and (p_2) were kept identical during the experiments.

A comparison of the Q-factor measurements for the I and Q component for the direct measurement with 24 GHz (blue trace) and the measurement with the proposed method and 4 GHz bandwidth (red trace) are shown in Figs. 3(a) and (b). The black trace shows the Q-factor, which can be achieved, if a signal with only 8 Gbd is directly measured with a 4 GHz detector. Due to the insertion loss of the MZM and the additional noise by the EDFA, the proposed method for the detection of the 12 GHz signal in the 4 GHz bandwidth (red trace) shows a little lower quality than the detection of a 4 GHz signal in a bandwidth of 4 GHz (black trace). But, it brings a Q-factor improvement of 2.2 dB compared to the detection of a 12 GHz signal in a 12 GHz bandwidth (blue trace). The corresponding constellation and eye diagrams for the direct detection and the proposed method are shown in Fig. 3(b) and (c), respectively.

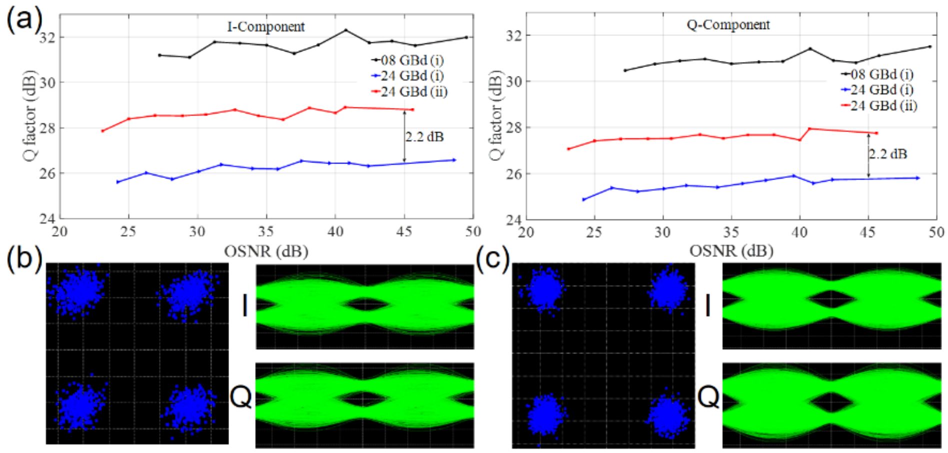

Fig. 3 (a) I and Q component of the Q-factor measurements for the detection of a 12 GHz signal in a 12 GHz bandwidth (blue), a 4 GHz signal in a 4 GHz bandwidth (black) and a 12 GHz signal in a 4 GHz bandwidth with the proposed method (red). The constellation and eye diagrams for direct measurement (b) and the proposed method (c).

4. Conclusion

In conclusion, the detection and processing of high-bandwidth wireless signals with low-bandwidth detectors and electronics based on time-interleaving and frequency-time coherence sampling was demonstrated. A 24 GBd QPSK signal, limited to its Nyquist bandwidth of 12 GHz was measured by a 4 GHz, three-branch system, leading to a 2.2 dB Q-factor improvement. Increasing the number of branches will further decrease the bandwidth requirements and will thus improve the resolution of the detection. Since only low bandwidth standard equipment is needed, the method can straight forwardly be integrated into any photonics platform and may be a solution to keep pace with increasing data rates and bandwidths in communications, radar and lidar applications.

5. References

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