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Demonstration of all-optical format conversion from wavelength-hopping time-spreading to non-return-to-zero

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Abstract

We present a novel design for all-optical conversion from wavelength-hopping time-spreading to non-return-to-zero format using wavelength converters based on semiconductor optical amplifiers. The multi-pulse nature of the wavelength-hopping time-spreading signal is utilized to achieve efficient, high-performance format conversion without pulse replication. The operation is demonstrated with a power penalty of 1 dB. A novel, complete design for interfacing wavelength-hopping time-spreading networks to WDM networks is also presented.

Keywords: CDMA; Format conversion; Access networks; semiconductor optical amplifiers

1. Introduction

There has been a widespread interest in the last decade or so for the introduction of optics into the access domain [1]. The network requirements and constraints for access networks are quite different from those in metro networks. While short-term constraints might delay the introduction of optics in access domain, long-term bandwidth requirements will make it inevitable [2]. Access networks are expected to prefer passive implementations over active switched Ethernet-type implementations due to the inherent simplicity in control and maintenance of passive networks. Therefore, passive optical networks (PON) have been widely studied and various standards have been agreed on [3]. However, most of these designs, being based on time-division-multiplexing (TDM) technology, do not scale very well and do not provide dedicated broadband service [4]. Both WDM and optical code division multiple access (OCDMA)-based PON designs have been of interest in this scenario for providing dedicated broadband service with 'triple-play' (voice, video and data services).

Wavelength-hopping time-spreading (WHTS) OCDMA offers several promising features for an access network – true asynchronous access, on-demand bandwidth allocation [5] and support of multiple traffic types requiring different bit rates and performance requirements [6]. In addition, its graceful degradation of performance and robustness to environmental fluctuations will be of high value in the access domain. On the other hand, metro-area networks and long-haul networks of the future could continue to use WDM schemes. Most these networks currently use non-return-to-zero (NRZ) format. While there is consensus that under non-linear fiber propagation, NRZ format may not be optimal [7], there could still be legacy networks which continue to use NRZ formats. Future photonic networks conceivably could consist of access networks based on WHTS, and WDM-based metro and wide area networks. For avoiding electronic bottlenecks, it is preferred that the interfaces between WHTS access networks and WDM metro networks be all-optical.

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In this paper, we present an all-optical, efficient technique for format conversion from WHTS to NRZ using SOA-based wavelength converters [8]. Experimental results are presented demonstrating this operation with a power penalty of 1 dB. A complete interface design for connecting WHTS networks to WDM networks is also presented.

2. Working principle

As WHTS signals comprises several return-to-zero (RZ) pulses of different wavelengths, it is instructive to understand format conversion techniques from RZ to NRZ first. Various schemes have been proposed for RZ to NRZ format conversion [9–11]. While SOA-based wavelength converters have been used to demonstrate high-speed RZ to NRZ conversion [11], the requirements for high-performance output NRZ signals place conflicting requirements on the SOA recovery time. Low recovery times are needed for obtaining sharp rising/falling edges of the NRZ signal and for pattern independent operation, while high recovery times are needed for flatter tops of the output NRZ signal. A pulse replication scheme was demonstrated earlier [12], to overcome this tradeoff, and provide high performance RZ to NRZ conversion. The replicated pulses serve to maintain the SOA in saturation, thus offsetting the recovery of the SOA due to current injection. Clearly, as the number of replications is increased, the output NRZ signal has better quality [12].

As WHTS signals comprises RZ pulses of different wavelengths, they can be de-correlated using standard WHTS decoder technology to obtain similar high performance. Note that while a WHTS decoder typically superimposes the different-wavelength RZ pulses to form the autocorrelation peak, in this application the de-correlator aligns the different pulses uniformly across the bit period for optimal format conversion. Fig. 1 explains this principle of operation. As SOA-based wavelength converters have high gain bandwidths, the performance is not significantly affected by the multi-wavelength nature of the WHTS signals. Note that the use of WHTS decoder for de-correlation implies that lossy pulse replication schemes can be avoided. As the code weight, i.e., the number of RZ pulses within the code, increases the performance of the output NRZ signal is also improved.

3. Experimental setup and results

A 4-node, 4-λ WHTS testbed [6], operating at 253 Gchip/s and 2.5 Gb/s was used to demonstrate the format conversion technique. Fig. 2 shows the schematic of the experimental testbed. The four-wavelength source for the WHTS signals was obtained by spectral slicing of supercontinuum using thin film filter (TFF)-based WDM demultiplexer (DEMUX). The supercontinuum was generated by passing the output pulse train from an actively mode-locked erbium doped fiber laser through 1 km of dispersion decreasing fiber. A $2^{31}-1$ pseudo-random bit sequence was modulated onto the supercontinuum before spectral slicing. The pulse trains at the four wavelengths, 1546, 1550, 1554 and 1558 nm, had an optical pulse width of 1.6 ps and were distributed to all the four transmitter (Tx) modules using power splitters. The independence of the data patterns between the different transmitters was ensured by inserting random delays between the outputs of the different transmitters. Note that in this experiment, each of the four users obtains a guaranteed 2.5 Gb/s data rate. In comparison, current PON implementations provide aggregate data rates of 622 Mb/s. For typical PON sizes (~32 customers), this gives an average data rate of ~20 Mb/s per customer. Thus, WHTS provides significant potential for scalability over current TDM-based PON implementations.

The code family used for this testbed was the carrier-hopping prime codes with 4-λs and 101 chips, with each

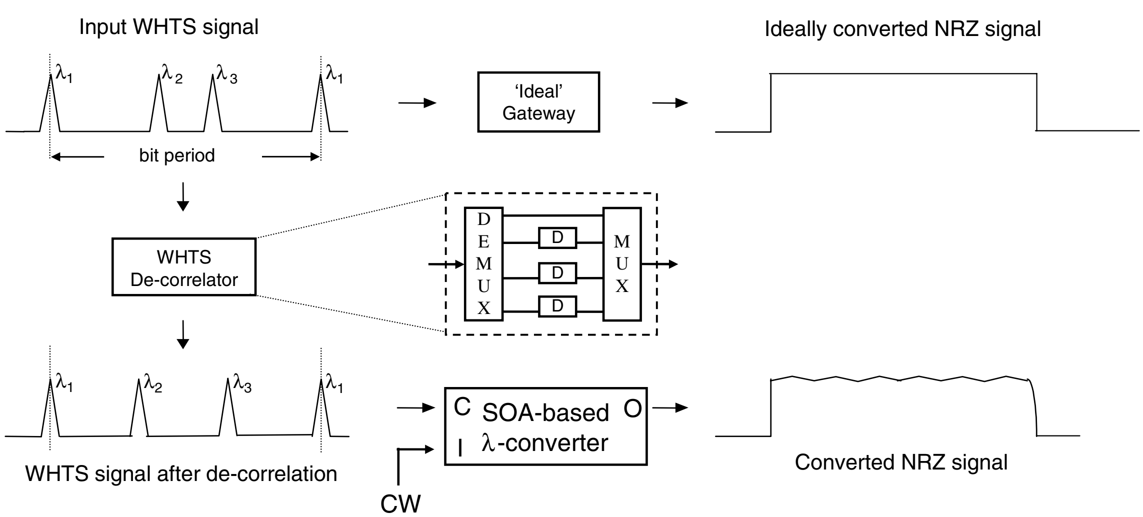

Fig. 1. Principle of operation for format conversion from wavelength-hopping time-spreading to non-return-to-zero using a WHTS de-correlator and SOA-based wavelength converter. The C, I and O ports of the wavelength converter are the control, input and output ports, respectively. CW: continuous wave.