Distributed Transversal Filters for GVD Compensation in Multi-Wavelength Optical CDMA Networks

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Abstract: We experimentally demonstrate a flexible electronic compensator for Group Velocity Dispersion induced time skewing in multi-wavelength Optical CDMA systems. The compensator uses a distributed transversal filter already proposed in the context of Optical Communications. This paper also describes a method to obtain the ideal transversal filter coefficients through modeling of the Optical CDMA network. Results show improvement in the ability to detect the autocorrelation peak in presence of Multi-Access Interference.

1 Introduction

Wavelength-Hooping Time-Spreading (WHTS) Optical Code Division Multiple Access (OCDMA) allies traditional advantages of OCDMA with increased code design flexibility and improved network performance [1]. A key drawback of multi-wavelength OCDMA systems is the dispersion-induced temporal skewing among wavelength channels which compromises the detection process; if the network induces relative temporal shifting between the wavelengths, the code pattern is distorted giving rise to errors in the receiver. This problem has been addressed before [2] and proposed solutions rely on a combination of Arrayed Waveguide Gratings (AWGs) and precisely configured optical delay lines [2]; these solutions are costly and difficult to implement in practice.

Electronic post-detection processing is a potential solution and has traditionally been ignored as it is believed to be unable to cope with the ever increasing speed of Optical CDMA proposals. In fact, it is empirically known that conventional Integrated Circuit (IC) topologies rarely operate at frequencies higher than 40% of the transistors cut-off frequency. However, recent advances in IC technologies (CMOS, GaAs, InP, etc.) in conjuction with distributed IC topologies [3], allow the design of ICs operating across a wide range of frequencies from near DC up to (and beyond) OCDMA chiprates of practical interest. A structure with such characteristics is the electronic distributed amplifier, which may be configured as a simple multi GHz amplifier/transversal filter/compensator [3] and has been reported for CDMA applications [4] over optical fibre.

We propose a front end receiver structure based on the distributed transversal filter in order to correct the correlation peak distortion resulting from temporal skewing among wavelength channels. This allows not only tunability of compensation parameters but also tunability across different code words, thereby resulting in a flexible, adaptable and efficient solution. The experimental results in this paper have been presented in the conference LEOS Summer Topicals 2009.

2 Concept and System Optimization

Analog transversal filters have been used in a variety of applications to combat optical system impairments [3]. However, analog electrical signal processing has never been proposed in the context of Optical CDMA networks. In this work the Optical CDMA signal is decoded in the optical domain using traditional methods (for example, an array of Fiber Bragg Gratings [1]) after which it is received with a photodetector. The compensator is an electronic distributed transversal filter with the frequency response described by the equation 1 [3]:

$$H_{TF}(\omega) = \sum_{k=0}^{N-1} G_k exp(-j\omega kT) \tag{1}$$

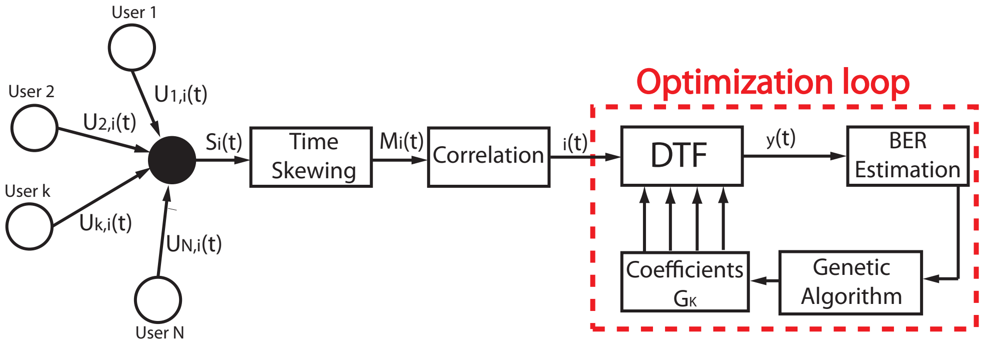


Figure 1: *Modelling diagram of a star OCDMA system including a Distributed Transversal Filter (DTF)*

where N is the number of stages of the transversal filter, T is the temporal spacing between transversal filter taps, G_j is the gain coefficient of the stage j.

Figure 1 shows the complete simulation model. For each network scenario (comprising a time skewing regime and a number of active users), there is combination of the transversal filter coefficients G_j that maximize the performance of the system. This ideal combination is determined through optimization of the system according to the loop presented in figure 1.

The first optimization algorithm considered was the Nelder-Mead “simplex”. This algorithm can be classified as a “direct search method”. This optimization method is easy to program, does not require derivatives, and is often claimed to be robust for problems with discontinuities or where the function values are noisy. However, Nelder-Mead “simplex” algorithm is susceptible to being trapped by local minima. This is particularly problematic in the optimization of the transversal filter because this device is redundant in the sense that different gain coefficient combinations can give rise to the same output. This led the optimization process to converge to a local minimum of the BER function.

In order to overcome this problem, Genetic Algorithms (GA) were chosen as optimization method. Genetic algorithms are known for exploring larger input variables combinations (larger spaces) and therefore for being less prone to converge to a local minimum. The idea behind this algorithm is the survival of the fittest individuals. In nature, stronger individuals have higher probability of survival and reproduction, originating descendants. These are likely to be as well or better adapted to environment than their parents, because they inherit their favourable genes. On the other hand, weaker individuals have lower probability to reproduce. Therefore, future generations are likely to be more adapted to the environment that the preceding ones. This process forms the base of natural selection introduced by Darwin and it is considered a central element in the modern theory of evolution.

All transversal filter gains span from zero to a maximum gain which, for simulation purposes, will be set to unity. Since the value of each individual tap gain only has significance in relation to the others, it is possible to define the central tap gain as one and optimize the remaining variables. Therefore, the optimization problem has (N-1) variables for the optimization. The goal of the optimization process is to minimize the BER function of the system shown in figure 1.

3 Experimental Setup

Fig. 2 shows the proof-of-concept prototype; a Fiber Bragg Grating based OCDMA network for 2.5 GBit/s transmission (20 GChip/s). The system comprises five CW Semiconductor Distributed Feedback Lasers with central wavelengths separated by 200 GHz (1548.20 to 1554.50 nm). The pulses are obtained with a Mach-Zehnder interferometer set to modulate an alternate sequence of zeros and ones (effectively repeating a pulse every 800 ps). The optical signal is then divided in a 1:3 splitter. Three FBG arrays are used to encode the WHTS codewords shown in Fig. 3. After encoding, a 3:1 coupler is used to couple the three users to the optical fibre. The transmission medium is a 40.5 km Single Mode Fibre (SMF) followed by a 5 km Dispersion Compensation Fibre (DCF). The receiver module comprises a 30 GHz

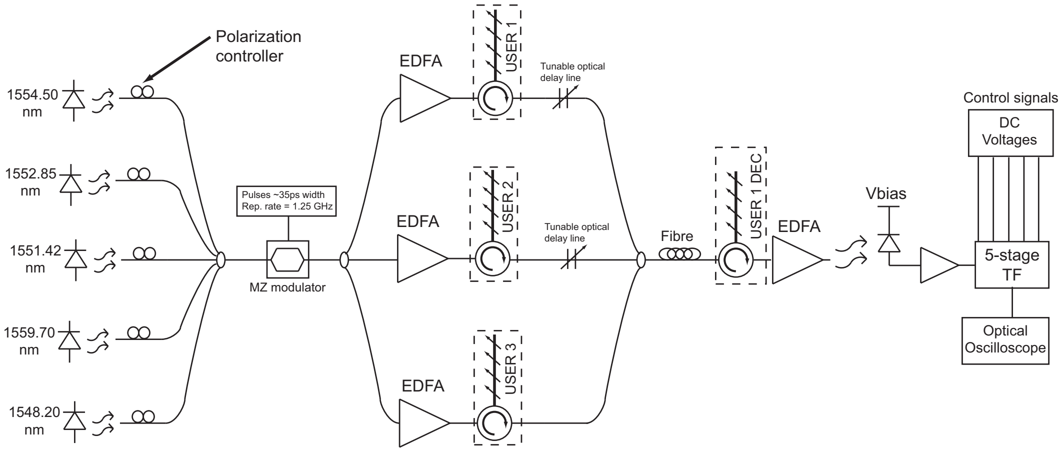


Figure 2: *Experimental setup of the Optical CDMA system*

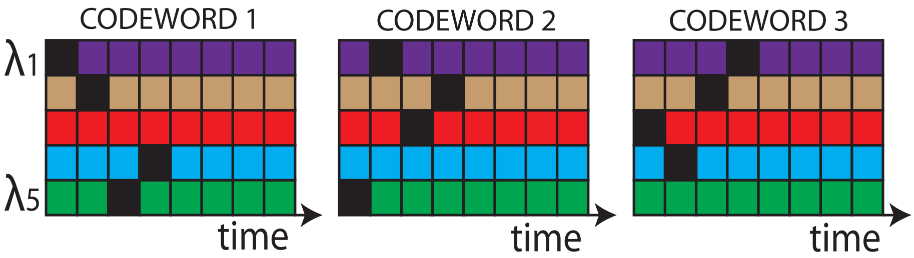


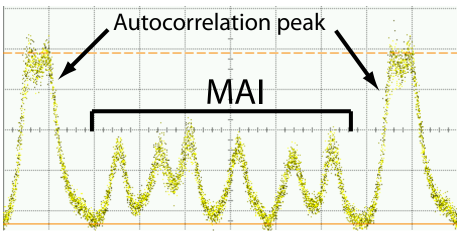
Figure 3: *Optical Orthogonal Codewords*

receiver and a trans-impedance amplifier. A five-stage Gallium Arsenide Distributed Transversal Filter with 18 ps of delay between adjacent stages is used to compensate residual dispersion [5]. The results are observed using an Optical Oscilloscope.

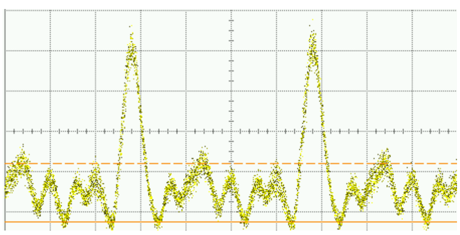
4 Experimental Results

To assess the performance improvement, we introduce the parameter auto-correlation intensity peak to the cross-correlation level ratio (P/C ratio). Two scenarios are analysed. In the first scenario, the cross-correlation function from users two and three do not have any chip coincidence. This is done by adjusting the tunable optical delay lines after the encoder. In the second scenario analyzed in this section, the cross-correlation functions are deliberately delayed so that they have two chips coinciding in time. This corresponds to the worst case scenario because the cross-correlation peaks achieve their maximum value and the P/C ratio is the worst possible. The transversal filter gains were set manually to maximize the P/C ratio.

Figures 4 and 5 show the compensation results for the first scenario and second scenario, respectively. In both cases, 50% improvement is evident; P/C ratio improves from 2 to 3 in the first scenario and

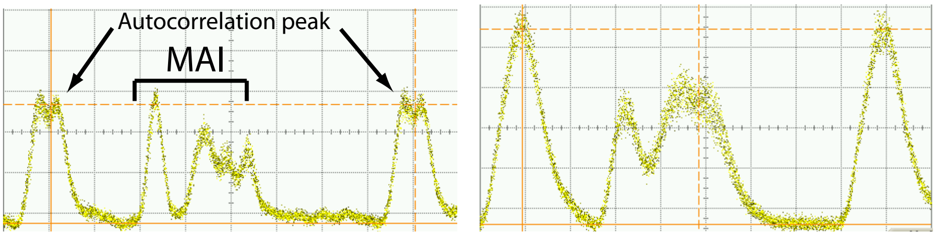


(a) Non-compensated (Time: 100 ps/div)



(b) Compensated (Time: 200 ps/div)

Figure 4: *Snapshot of the received signal with no coincidence in cross-correlation*



(a) Non-compensated (b) Compensated

Figure 5: *Snapshot of the received signal with coincidence in cross-correlation (Time: 100 ps/div)*

from 1 to 1.47 in the second. Note that the extent of the autocorrelation peak compensation is ultimately limited by the interactions between the cross-correlation chips. This is especially obvious in figure 5(b); if the gain coefficients continue to rise, the peak value of cross-correlation will rise at faster pace than the autocorrelation peak. Therefore, the ideal coefficients provide the best balance between cross-correlation peaks and the autocorrelation level.

5 Conclusion

The use of electronic post-detection processing is proposed and experimentally demonstrated in the context of Optical CDMA networks for the first time. Results show 50% improvement in the autocorrelation peak in relation to the cross-correlation level and therefore potential improvement the performance of the system.

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