Programmable Optical Buffering using Fiber Bragg Gratings combined with a Widely-Tunable Wavelength Converter

Chin-Hui Chen, Leif A. Johansson, Vikrant Lal, Milan L. Mašanović,
Daniel J. Blumenthal and Larry. A. Coldren
Department of Electrical and Computer Engineering, University of California, Santa Barbara, CA 93106
janet@ece.ucsb.edu

Abstract: A 40Gbps RZ all-optical buffering method implemented by FBG and tunable wavelength converter is presented. Preliminary results of time-delay up to 7μs and pulse broadening were measured. System measurements at 10Gbps show desired delay programmability.

OCIS codes: (060.2330) Fiber Optics Communications; (060.2360) Fiber Optics links and subsystems

1. Introduction

In proposed all-optical packet-s witched networks [1], optical buffering is required to avoid contention issues. Contention occurs when more than one packet of the same wavelength competes for the same output port at the same time. Thus, buffering is essential to many optical packet switch implementations. In order to eliminate the extra optoelectronic conversions and the inefficiency of existing electronic system, all-optical buffering is being widely investigated.

In this paper a method of all-optical buffering that can provide a large number of rapid selectable [2] discrete delay values with low insertion loss and long available maximum delay is presented and demonstrated. The main idea is illustrated in Fig.1 in which Fiber Bragg Gratings (FBG) and wavelength converters (WC) are used to implement wavelength-dependent delay lines. In the proposed method an incoming packet is converted by a rapid-tunable WC to a specific wavelength which is controlled by an external decision signal, and the desired delay value is mapped to the wavelength domain by cascaded FBG elements. Various implementations of wavelength conversion have been presented [3,4,5], specifically the wavelength converter, integrated with SGDBR, used in this work is described in [6].

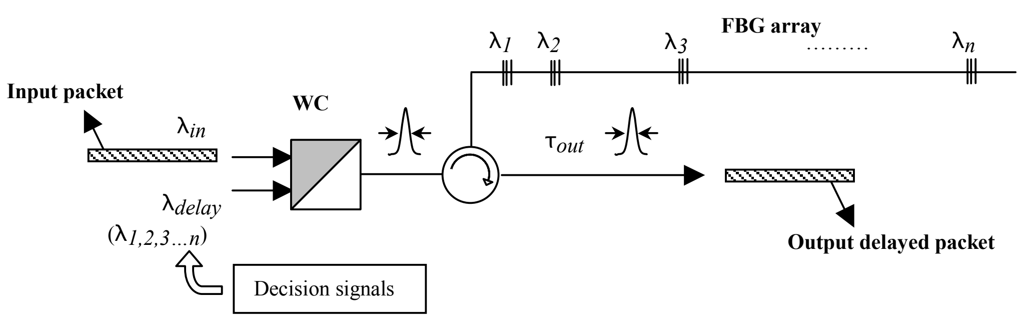

Fig. 1. System concept for optical buffering implemented by FBGs and wavelength converters (WC).

2. FBG buffer design

This system was designed to be compatible with a 40Gbps RZ communication system, in which less than 12.5ps reflected pulse width is required, and therefore a grating bandwidth ≥100GHz is needed. A 200GHz channel spacing was chosen to keep adjacent channel crosstalk below –20dB. With the selected channel spacing, up to 25 discrete delay values can be reached using an all-optical wavelength converter based on a rapid-switchable widely-tunable SG-DBR laser with a tuning range exceeding 40nm [6]. The design was aimed at satisfying performance targets of low group velocity delay (GVD) and moderately low loss, using a relatively simple structure suitable for low-cost manufacturing, considering of future expansion. A central tradeoff in the grating design is between peak reflectivity and GVD, by the means of changing grating burst length. Fortunately, for reflection-type delay line application, high in-band extinction is not necessary allowing the use of shorter gratings with less than the typical 99.9% peak reflectivity.

The final specifications of the FBG was a 2.5mm grating burst, raised cosine apodization and with an index contrast of □*n*= 0.0008. The use of a non-chirped grating was found to ensure low GVD and simple manufacturing. The modeled performance of the grating includes <5ps group delay variation and 80.9% peak reflectivity, resulting in less than 1dB insertion loss and a calculated impulse response with 6.3ps FWHM.

3. FBG buffer characterization

To demonstrate the functional feasibility, a system of four-FBG connected to a three-port circulator was established for the initial demonstration. The four FBGs with serial center wavelengths at 200GHz spacing were physically arranged on the order of 1552.5nm(FBG1), 1549.2nm(FBG2), 1550.9nm(FBG3), and 1553.8nm(FBG4). They were placed out of wavelength sequence in order to make the crosstalk measurement easily implemented. The fiber lengths among FBGs were designed to have logarithmic increments.

To demonstrate the achieved range of delay times, a relatively wide pulse (with ~7ns width) at a specific wavelength, equal to one of the FBG center wavelengths, was sent into the input port of the circulator, and the reflected delayed signal was checked by an oscilloscope. The result is shown on Fig. 2. and the time delay differences between the FBG1 and others are 29ns, 1.06μs, and 7.02μs, respectively. The non-uniform pulse intensity is here limited by the loss of each connection between components. The insertion loss can ultimately be reduced to the limit of the fiber transmission loss (<0.2 dB/km), which enables realization of very large buffer depths. Also shown in Fig. 2 is the combined reflection spectrum from the four FBGs. No grating crosstalk was evident in the time-domain data that was limited by the 30dB SNR of the measurement.

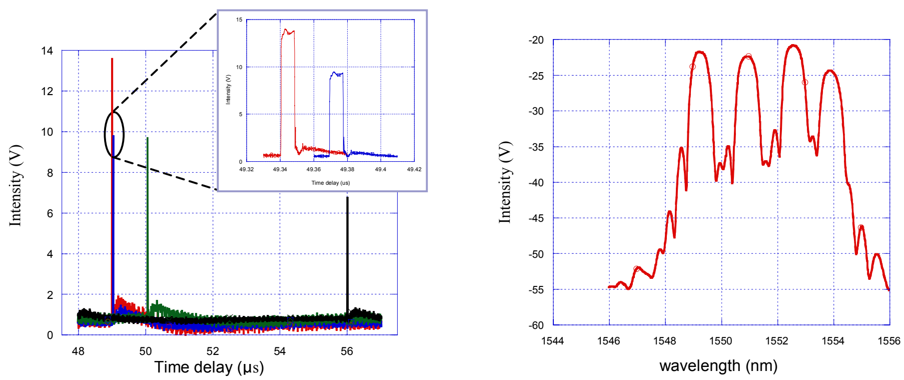

Fig. 2. **Left:** Different time delay values correspond to four discrete FBGs. The delay time differences between the FBG1 and others are 29ns, 1.06μs, and 7.02μs, respectively. The inset is the detail of the first two reflected pulse. **Right:** The reflection spectrum from the four FBGs. The non-uniform peak intensity of each FBG is here mainly due to interconnect loss.

To measure the dispersion properties of the buffer a narrow pulse source was used. The pulse width was measured by an autocorrelator. Two measurements were performed. In the first measurement, a tunable wideband pulse source with the pulse width of 1.24ps at a selected wavelength was sent into the system, the output signal was passed through a filter to define the specific wavelength, and then was received by an autocorrelator. The obtained data is shown in Table 1. The raised-cosine FBG weighting function provides a Gaussian-like reflected pulse with no apparent side lobes in the time domain. The broadened pulse width is around 5ps for shorter lengths of fiber, which confirms the simulation and the initial design. For the 5-6 ps pulse widths achieved using the all-optical wavelength converters reported elsewhere [5], the resulting delayed pulse-width will remain well within the 12.5 ps FWHM requirement stated above. At the longest buffer time delay, 7.02μs, some excess pulse broadening is observed due to fiber dispersion. If even longer buffer delays need to be achieved, dispersion managed fibers, possibly combined with some amplification, could be used to preserve the signal.

In the second measurement, a negatively chirped pulse with 12.47ps width was used as the input signal, and a compressed output pulse width of 10.47ps was obtained. Since the FBG has a positive dispersion characteristic, as it combines with a negatively chirped pulse source, the pulse was compressed by the grating. Pulse broadening depends on pulse chirp, fiber and FBG dispersion, and FBG bandwidth, therefore, pulse compression is possible with a proper combination of FBG dispersion and pulse characteristics, and was realized in this experiment.

Table 1. Measurements summary

	FBG1 1552.5nm	FBG2 1549.2nm	FBG3 1550.9nm	FBG4 1553.8nm
Δ(Time delay) to FBG1	0	0.029μs	1.06μs	7.02μs
Fiber length to FBG1	0	2.9m	106m	702m
Pulse width τ_{out} (1.24ps wideband input)	5.97ps	4.49ps	5.48ps	8.14ps
Compressed pulse widthτ_{out} (12.47ps negatively-chirped input)	-	-	-	10.47ps

4. Systems demonstration

To demonstrate the proposed buffering function, a preliminary 10Gbps system is presented here. A modulated signal at λ_{in} is sent in to a rapidly-tunable WC and converted to a desired wavelength λ_{delay} which equals to one of the FBG center wavelengths by tuning the front and back mirror and phase sections of the SGDBR integrated in WC. A filter is placed to ensure no undesired signal exists and the output is fed to an oscilloscope. The system setup and results are shown in Fig.3. In the eye diagrams, a promising result is demonstrated that no apparent degradation is found after sending into the FBG array. It can be further confirmed by extinction ratio that after WC conversion it is measured to be 10.5dB and keeps unchanged for all the system. It is noticed that the eye of FBG4 is a little bit noisier than other channels due to the additional interconnect loss and could be improved by a better connection.

Based on this systematic demonstration combined with the time delay and pulse broadening measurements, a programmable optical buffering method has been established and demonstrated. It is also believed in the future success at 40 Gbps systems.

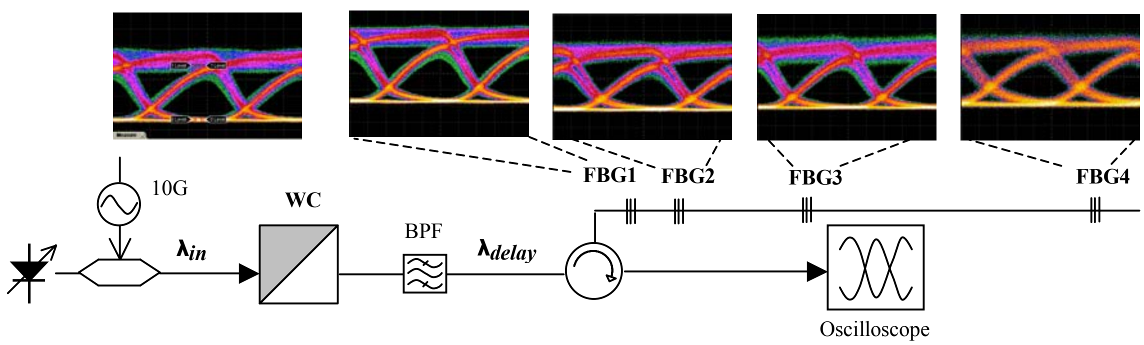

Fig. 3. Optical buffering in 10Gbps system setup and the eye diagrams of the input and four output channels.

5. Conclusion

A large number of rapidly selectable discrete delay values with low insertion loss and long available maximum delay can be achieved by the proposed method of all-optical buffering using FBGs and rapidly-tunable WCs. A FBG buffer working at 40Gbps for an RZ system has been designed and programmable time delays from tens of nanoseconds to microseconds have been obtained. It is also confirmed that the pulse broadening effect is within an acceptable range for a 40Gbps RZ system. A preliminary 10Gbps four-element FBG system has been built to demonstrate its functionality and a promising result of no apparent degradation is also achieved. According to these initial measurements and demonstrations, it is believed that the proposed method has a great possibility to work at 40Gbps.

This work is supported by the DARPA/MTO LASOR Program under Grant No. W911NF-9-0001.

6. References

[1] Blumenthal, D.J. *et al*. Communications Magazine, IEEE, vol. 41, No. 2 , Feb. (2003)
[2] John E. *et al*. IEEE *Photonics Technology Letters*, vol. 15, No. 8, Aug. (2003)
[3] N. Edagawa *et al*. Conference on Optical Fiber Communication. OSA Technical Digest Series. vol. 6, (1997)
[4] P.S. Cho *et al*. IEEE *Photonics Technology Letters,* vol. 11, pp1662-4, (1999)
[5] Sysak, M.N. *et al*. *Photonics Technology Letters*, IEEE, vol. 16, No. 9, Sept. (2004)
[6] M. L. Mašanović *et al*. IEEE *Photonics Technology Letters*, vol. 16, No. 10, (2004)
[7] V. Lal *et al*. submitted to OFC (2005)