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$1\times N$ wavelength selective adaptive optical power splitter for wavelength-division-multiplexed passive optical networks

Feng Xiao*, Haithem Mustafa, Kamal Alameh

Electron Science Research Institute, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027, Australia

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ABSTRACT

In this paper, a $1\times N$ wavelength selective adaptive optical power splitter (WS-AOPS) suitable for wavelength-division-multiplexed passive optical network (WDM-PON) systems is proposed and experimentally demonstrated based on the use of an Opto-VLSI processor. The input signals with different wavelengths can be split and coupled into N output ports with variable splitting ratios. A proof-of-principle 1×2 WS-AOPS structure driven by optimized multicasting phase holograms uploaded onto the Opto-VLSI processor is developed, demonstrating an arbitrary splitting ratio for each input wavelength channel over C-band.

1. Introduction

Passive optical network (PON) has been considered the most promising solution to the access network due to its capability of delivering future high-speed broadband integrated services to a large coverage area with ease of maintenance and upgrade [1]. The PON architecture is a point-to-multipoint system that connects multiple users to an optical line terminal (OLT) at the central office using a standard single-mode fiber. Currently the time division multiplexing (TDM) PON system has been widely deployed, which uses optical power splitters to enable customers to share on a single wavelength by using allocated time-slots. Since only one wavelength is used for downstream data and one for upstream data, shared by all users, a limited average bandwidth per user could be offered although recently the 10-Gbit/s TDM-PON system has been developed. Incorporation of wavelength division multiplexing (WDM) into PONs has been considered an ideal solution to extend the capacity of TDM-PONs without the need to dramatically change the fiber infrastructure [2]. WDM PON supplies users with one or more wavelengths rather than sharing a wavelength among 32 or even more users in TDM PON, thus allowing each user to access the full bandwidth accommodated by the wavelengths. Furthermore, each wavelength link in a WDM PON network can be operated as virtual point-to-point connection at a different speed and with a different protocol for maximum flexibility. The main disadvantages of the WDM PON technology include high cost and relative immaturity, mainly because of the need for many WDM light sources and wavelength-specified optical network units (ONUs). In addition, further work is required on common issues in WDM-PONs such as efficient broadcast services delivery, fault monitoring and independent service provisioning [3]. A more practical solution for near-future deployment is the hybrid WDM/TDM PON [4,5], in which each wavelength is shared among several ONUs rather than being dedicated to a single ONU. Such WDM/TDM PON systems can simultaneously achieve low per-subscriber cost and scalability to increase the number of subscribers, while still maintaining a relatively high per-subscriber bandwidth [6].

In currently deployed PON systems, passive optical splitters and/or arrayed waveguide gratings (AWGs) are widely used. Based on using current passive optical power splitters and AWGs, these architectures will experience extremely high power losses, making their deployment impractical [7]. Recently, some adaptive optical power splitters have been reported [8–11], attracting great attention, due to their potential applications in the rapid deployment of PONs. However, future PONs require more advanced optical splitter functions. For example, in a fully flexible architecture of hybrid WDM/TDM PONs, each wavelength needs simultaneously be routed to any TDM PON ONU. Splitting a wavelength signal equally to multiple output ports has been reported [12,13]. However, adaptively splitting any wavelength channel to any output port with arbitrary splitting ratios is a key function required by the next generation of PON systems.

In this paper, we propose and experimentally demonstrate the concept of a $1\times N$ wavelength selective optical power splitter (WS-AOPS) architecture, for WDM PONs applications, based on the use of an Opto-VLSI processor as an adaptive optical beam splitter. Fig. 1 shows the basic function of the proposed $1\times N$ WS-AOPS.

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* Corresponding author.
E-mail address: f.xiao@ecu.edu.au (F. Xiao).

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The input WDM signal contains channels of wavelengths $\lambda_1, \lambda_2, \ldots, \lambda_M$, with different intensities, each channel can be independently split into N output ports with an arbitrary splitting ratio. While the primary aim of this paper is to demonstrate the capability of the proposed $1 \times N$ WS-AOPS architecture to simultaneously route any wavelength channel to any ONUs in a WDM PON network with any splitting ratio, this architecture could also find application in optical metropolitan area networks (MANs) when a wavelength channel needs to be simultaneously routed along different paths.

2. Proposed optical power splitters

The proposed $1 \times N$ WS-AOPS architecture is shown in Fig. 2. A fiber collimator array comprised the input fiber port and the output fiber ports. Wavelength channels were launched through the input fiber port, collimated by a lens array, and diffracted by a grating plate along different directions. Another lens was used to map the diffracted signals onto the active window of an Opto-VLSI processor.

The Opto-VLSI processor is an adaptive optical diffractive element that comprises an array of liquid crystal (LC) cells whose phase levels are electronically switched by a Very-Large-Scale-Integrated (VLSI) circuit. By using an optimized multicasting phase hologram, a collimated Gaussian beam incident onto the Opto-VLSI processor can adaptively be diffracted along different directions with arbitrary optical power splitting ratios. The splitting angle resolution is given by [11]

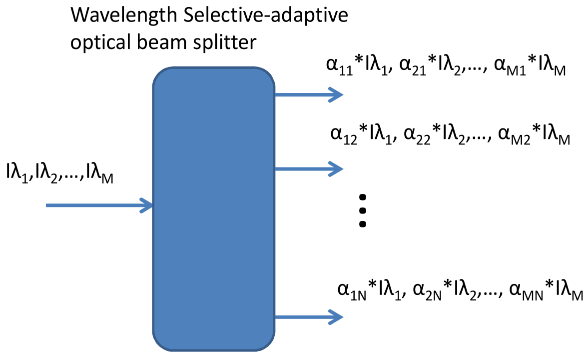

Fig. 1. Function of a wavelength selective adaptive optical power splitter.

$$\alpha = \arcsin\left(\frac{\lambda}{N \times d}\right) \tag{1}$$

where λ is the optical wavelength, N is the number of illuminated pixels, and d is the pixel pitch.

If no hologram was uploaded onto the Opto-VLSI processor, the optical signal reflected back into the input port, where a fiber optical isolator was employed to prevent the reflected light from coupling into the light sources. After WDM demultiplexing by the grating plate, each wavelength channel illuminated in a small pixel block of the Opto-VLSI processor. By uploading a multicasting phase hologram onto this pixel block the corresponding wavelength channel was independently split, with arbitrary splitting ratios.

3. Experiments and discussions

A proof-of-concept 1×2 WS-AOPS demonstrator was developed using a 256-phase-level two-dimensional Opto-VLSI processor having 512×512 pixels with 15 μm pixel pitch. The 1200 line/mm blazed grating plate was placed before a lens of 100 mm focal length in order to map the whole C-band spectrum onto the 7.68 mm-wide active window of the Opto-VLSI processor. The optical beam size in the vertical direction was ~0.7 mm, covering around 48 pixels at the Opto-VLSI window. An optical spectrum analyzer with 0.01 nm resolution was used in conjunction with an optical switch in order to monitor the optical signals coupled into the two output fiber ports. For each wavelength channel, a computer algorithm based on simulated annealing was used to optimize the multicasting phase hologram needed for a target optical beam splitting scenario.

In the first experiment, three wavelength channels, each of 120 μw optical power, were multiplexed and launched into the input fiber (Port 2) and the output optical signals at Port 1 and Port 3 were monitored. For each wavelength channel, a 50×48-pixel beam splitting hologram was generated and uploaded onto the pixel block illuminated by the corresponding optical beam. A splitting profile ($1{:}r_1$, $1{:}r_2$, $1{:}r_3$) corresponds to a scenario where the input wavelength channels (λ_1, λ_2, and λ_3) launched into Port 2 are split to the output

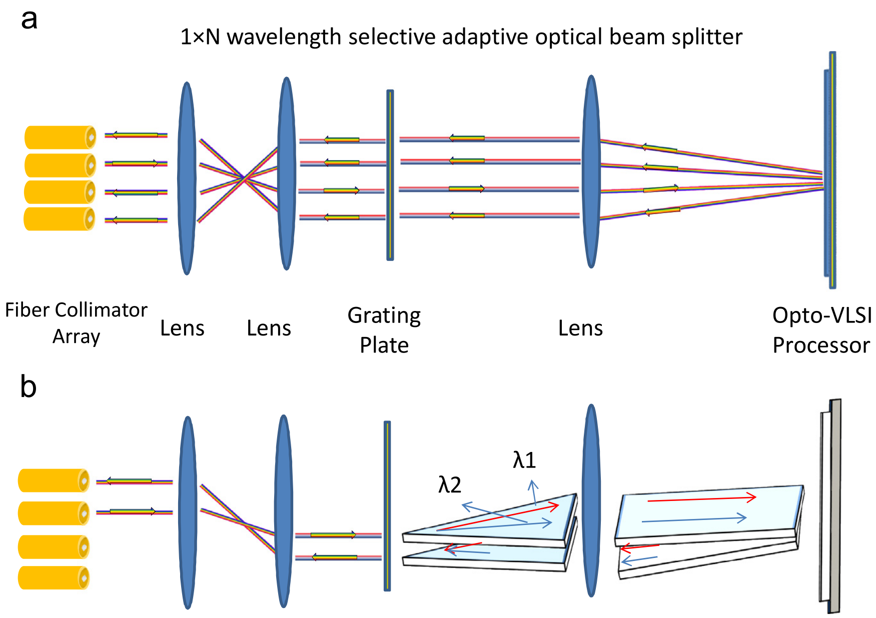

Fig. 2. Proposed $1 \times N$ wavelength selective adaptive optical power splitter.