Comparative Analysis on various Methods of Spectrum Slicing

Nelsa Abraham[1] Lijeesh Kumar A[2]
[2]P.G. Scholar
[1,2]Department of Electronics and Communication Engineering
[1,2]Government Engineering College, Barton Hill, Thiruvanathapuram, Kerala, India

Abstract— Optical fiber becomes the fundamental means of transmission in the communication area. Spectrum slicing technique is very useful technique which mostly used nowadays in many communication systems due to its large capacity handling capability. The main advantage of spectrum slicing is that it is more power efficient and less costly than traditional laser technology. Mostly spectrum slicing can be done by using wavelength division multiplexing (WDM) and array waveguide grating (AWG). Semiconductor optical amplifier (SOA) can be used to reduce the intensity of noise in spectrum sliced WDM system. For the past decades of time several works are going on different spectrum slicing technique and the effects of slicing in optical communication system. This paper reviews about various spectrum slicing techniques used in optical communication system.

Key words: Spectrum Slicing, Wavelength Division Multiplexing, Passive Optical Network, Array Waveguide Gratings, Crosstalk, Semiconductor Optical Amplifier

I. INTRODUCTION

Spectrum slicing technique of light sources has been using more than two decades for the modulation of optical signal. Several researches are going in this area because of its various advantages. In this different slice of same spectrum is used to modulate. Spectrum slicing can be done by using wavelength division multiplexed (WDM), Array Waveguide Gratings (AWG) etc. The light sources can be Laser, Spatial led, ASE source etc. The spectrum of light source is passed through slicing devices which produces several slices of equal wavelength, in which each sliced spectrum can be used to modulate several signals.

Passive optical networks (PONs) have nowadays becomes the most leading contenders in the way to meet the demand for low-cost, high-bandwidth and access services. A detailed study of SOA-based noise reduction and its application to high channel density spectrum-sliced wavelength division-multiplexing (WDM) systems is necessary for the analysis. In recent years several studies has the subject of intensity noise suppression of spectrum-sliced wavelength- division multiplexing (SS-WDM) systems by semiconductor optical amplifiers (SOAs) that operates in deep saturation.

This paper explains different spectrum slicing techniques done by many research persons. These papers discuss about the spectrum slicing techniques and the factors affecting the system when spectrum slicing is performed. It is then compared with the previous methods that are not using spectrum slicing. Some of the methods used in this field are explained in the next section.

II. SPECTRUM SLICING TECHNIQUES

In 1998, D K Jung et al. in [1] invented a new wavelength division multiplexed passive optical network which is based on spectrum slicing technique. This architecture utilizes WGR's for both multiplexing upstream channels and demultiplexing downstream channels and viceversa. Spectrum sliced fiber amplifier light source is utilized as the light source in this method. EDFA is used to compensate the several losses occurred due to the usage of light sources. Downstream channels are operated in the region 1550nm and upstream in 1540nm. The main advantage of this method is that the cross talk occurring from simultaneous use of single WGR for both multiplexing and demultiplexing can be suppressed very easily by using two types of BPFs centered at these wavelengths.

In 1999, Y S Jang et al. in [2] explained the effect of cross talks in WDM systems that uses spectrum sliced light sources. The system performance of WDM cross connected network may degrade severely due to intra band cross talk generated at the input of neighboring fibers carrying same wavelength signals. The signal-crosstalk beat noise of the WDM system using spectrum-sliced light sources is given by

$$\sigma^2_{sig-cross} = 2I_s I_c \left(\frac{B_c}{B_0^2}(2B_0 - B_c)\right)$$

This signal cross talk in WDM networks can be reduced significantly by using spectrum-sliced light sources due to their relatively broad optical bandwidth. Another advantage is that the spectrum-sliced light source would allow much higher input power per channel than the laser sources since these light sources are relatively insensitive to the nonlinear crosstalk caused by FWM.

In 2002 Mingshan Zhao et al. in [3] invented that by using saturated semiconductor optical amplifier (SOA), intensity of noise can be reduced in spectrum sliced WDM systems. The most effective method for getting high noise suppression ratio and large bandwidth is to increase the bias current of the saturated SOA. The experimental setup for intensity noise reduction is shown in fig.1.

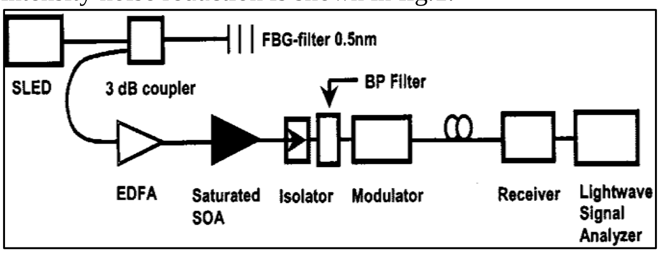

Fig. 1: Experimental setup for intensity noise reduction.

For the optimum operation of the SOA, an increase of 13.5 dB in the intensity-noise-limited signal-to-noise ratio (SNR) for a bitrate of 2.488 Gb/s and of17.5 dB for a bitrate of 622 Mb/s are obtained experimentally .These results provide useful information for the design and performance improvement of the spectrum-sliced WDM networks.

In 2004, Anoma D McCoy et al. in [4] gave effects of filtering in spectrum-sliced WDM System by the usage of SOA based noise reduction. Filtering of the broadened output degrades the signal quality, reducing the noise suppression benefits of the SOA. Filtering is required at the receiver to minimize crosstalk, thus imposing a tradeoff between channel crosstalk and intensity noise. The study clearly demonstrates the need to consider the effects of channel and receiver filter shape or width in the design of high channel count spectrum-sliced systems employing SOA-based noise reduction.

In 2005, Anoma D McCoy et al. in [5] formulated that by using SOA based noise reduction technique the signal quality in a spectrum sliced WDM can be improved. SOA can be used for signal modulation as well as amplification. This paper studies the effects of post SOA filtering using numerical simulations. It experimentally and numerically examined post SOA filtering effects and spectral distortion. Aligning the receiver filter to compensate for the red shift introduced by the saturated SOA produced an improvement of 3dB in the signal RIN. The receiver signal quality can be improved up to 11.5 dB by reducing the line width enhancement factor of the amplifier. The main advantage of this method is that it will increase system performance and allow for greater granularity and spectral efficiency in high channel count spectrum-sliced systems using gain saturated SOAs.

In the same year, David Forsyth and Michael Connelly in [6] explained that with the help of four waves mixing from SOA the spectrum sliced wavelength can be converted. Spectrum slicing is an established technique of dividing incoherent light using optical filters to generate large-scale multi wavelength light in bundles. The technique usually makes use of a single, inexpensive multi wavelength broadband source, such as the amplified spontaneous emission (ASE) from an erbium-doped fiber amplifier (EDFA), with some filtering effects added. The four-wave mixing (FWM) wavelength conversion technique involves the generation of a signal replica from two inputs. Efficient FWM is achieved when both inputs are co-polarized.FWM using coherent light has been studied extensively, but there are limited achievements on the subject using broadband light, except for work on FWM in dispersion-shifted fiber and work using polarized ASE instead of a coherent laser as the probe source into an SOA .The output FWM signal has improved RIN compared to the input signal. This technique has good potential for application in future local access spectrum-sliced networks, where wavelength conversion may be required.

In 2006, M S Leeson et al. in [7] gave that spectral slicing can be used for Data Communications. Spectrum slicing provides a cost-effective alternative to laser diode sources but introduces excess intensity noise due to the source incoherence. This paper describes about the bit error rate performance of SS systems and their capabilities. SS light wave systems have been considered for high speed data communications. PPM has been shown to offer a 3 dB sensitivity advantage for SS over OOK.

In 2007, Francesco Vacondio et al. in [8] explained the impact of SOA characteristics and data modulation speed on the noise reduction capabilities of SOA in SS-WDM PONs. There are two possible promising configurations: in the first of them the SOA is used as a booster at the OLT, in the second it is used to perform an incoherent-to-coherent conversion at the ONU. In the booster configuration at the OLT slow SOAs are more effective in cleaning the noise with respect to fast ones. In the conversion configuration at the ONU, fast SOAs are more effective for noise cleaning: for bit rates as high as 2.5Gb/s. The disadvantage of the conversion-based noise cleaning scheme is the need to saturate the SOA at the receiver so that XGM is efficient

In 2008 S B Sun and M S Leeson in [9] had done a performance comparison of spectrum-sliced WDM and Inherent Optical CDMA. The theoretical system capacities of a spectrum-sliced wavelength division multiplexing system (SS WDM) and an incoherent optical code division multiplexing access (OCDMA) system are compared. Both incoherent OCDMA and SS WDM systems have been analyzed and compared based on the same configuration. The results suggest that beat noise has negative effects on the performance for both systems. OCDMA throughput is also limited by the number of active users. The bandwidth expansion makes it less bandwidth-efficient than SS WDM.

In 2009, Amirhossein Ghazisaeidi et al. in [10] did a thorough numerical study of intensity noise mitigation of spectrum sliced wavelength-division multiplexing (SS-WDM) systems employing a nonlinear semiconductor optical amplifier (SOA) before the modulator. The simulator of the SS-WDM link, embedded inside a Multi canonical Monte Carlo (MMC) platform, estimates the tails of the probability density functions of the received signals down. It describes a simulation tool to evaluate the performance of optical links employing nonlinear SOAs. This simulator to study noise mitigation of SS-WDM systems by a premodulator SOA. The simulator can be useful as a design tool to optimize SS-WDM systems, as well as studying various SOA-based regenerative systems.

In 2010 Muthana. Y. Aldouri et al. in [11] introduced the improved versions of modified demultiplexers operating for 16 channel multi users with and without EDFA are proposed for slicing WDM systems. In this paper, they presented a new model of a demultiplexers used to operate as slicing system for 16 channels, the pumped EDFA is used in order to transmit the data to the user safely, with 200 Km fiber length, with one LED laser source constant at 0.5 dBm power input.

In 2012, Vjaceslavs Bobrovs et al. in [12] gave the improvement in the Performance of High Speed Spectrum-Sliced Dense WDM-PON System. In this work using OptiSim simulation software they realized an experimental high-speed spectrum-sliced DWDM PON system model where DCF fiber and FBG are used for accumulated CD compensation. The maximum achievable reach improvement of SS-DWDM PON system using proposed CD compensation methods has been investigated. Because of good filtering performance flat-top type AWG units were chosen for spectral slicing of ASE broadband noise-like light source. The maximum reach of realized SS-DWDM PON system without CD compensation was 10 km. It has been shown that by using described CD compensation methods DCF and FBG the maximum reach of proposed spectrum-sliced optical system can be improved significantly.

In the same year, MN Junita et al. in [13] invented that by using Wavelength Division Multiplexing with Laser and LED Spectral Slicing Architecture, hybrid Subcarrier

Multiplexing can be implemented. This paper demonstrates the architecture of hybrid subcarrier multiplexing Wavelength Division Multiplexing network combining light emitting diodes (LED) and Laser as the light sources. Eight equally spaced WDM channels transmitting 1Gbps data rates are combined with four subcarrier channels carrying 622Mbps data rates are combined and transmitted over a single fiber over a 10km distance. BER and eye diagrams proves that the ability of such system to operate simultaneously in one system design. Thus provides an alternative solution to network providers in designing network architecture based on customers' multi-rate demands with reduced implementation cost.

In the same year, Sandis Spolitis et al. in [14] gave reach Improvement of the Spectrum-Sliced Dense WDM-PON System, where amplified spontaneous emission (ASE) source is used as a seed light. The maximum achievable reach improvement of SS-DWDM PON system using proposed CD compensation methods has been investigated. Flat-top type AWG units were chosen for spectral slicing of ASE broadband noise-like light source because of good filtering performance. This type of AWG units provide good WDM channel separation and passes sufficient high optical power to provide sufficiently low bit error ratio BER**.** The operating principle of spectrum sliced WDM PON system is shown in fig.2.

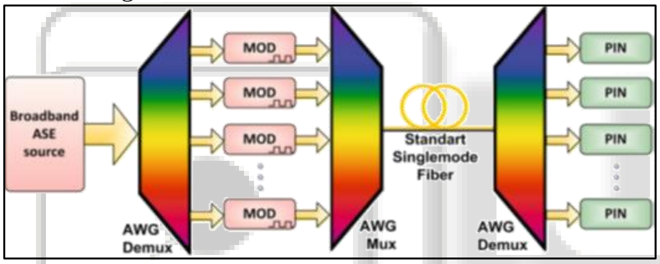

Fig. 2: Operating principle of spectrum-sliced WDM PON system

The maximum reach of realized SS DWDM PON system without CD compensation was 10 km, but it has been shown that using described CD compensation methods DCF and FBG the maximum reach of proposed spectrum-sliced optical system can be significantly improved.

In 2013, Hoon Kim in [15] gave the use of an ultra-narrow spectrum-sliced incoherent light source for transmission of 10-Gb/s non-return to zero signals for wavelength-division-multiplexed passive optical networks. In this light source, a broadband amplified spontaneous emission noise is spectrum-sliced by an ultra-narrow filter and then fed to a gain-saturated semiconductor optical amplifier to suppress the excess intensity noise of the incoherent light.

In the same year, Han Hyub Lee et al. in [16] demonstrated high efficient pre-spectrum sliced seed lights (PS-SL) for serving low cost seeded wavelength division multiplexing passive optical network (WDM–PON). The power, flatness and bandwidth of seed signal from the proposed PS-SL were sufficient to serve multiple seeded WDM–PON OLTs. By comparing with the commercial BLS, the PS-SL shows low power consumption due to the energy efficient design based on re-injection of spectrum sliced ASE light. The number of operating channels of PS-SL can be simply extended to 64 by using of an optical interleaver with periodic 50-GHz channel spacing. Also proposed the PS-SL shared multiple WDM–PON architecture. Considering the cost of components, volumetric size, and electrical power consumption, sharing the PS-SL with several WDM–PON OLTs will be an efficient approach to reducing the overall cost of seed light per OLT system.

In 2014, Abdel Hakeim M. Husein et al. in [17] realized and investigated high speed SS-DWDM system 32 channels with data rate up to 3 Gb/s using broadband ASE source (LED). The spectrum sliced dense wavelength division multiplexed passive optical network (SS-DWDM–PON) has been investigated as a power efficient and cost effective solution for optical access networks. AWG demultiplexer is used to operate as slicing system. It was found that the performance of investigated SS-DWDM–PON system is completely sufficient to provide transmission of information with data rate of 3 GB/s per channel with BER < 10^{-12} over the 40 km long fiber optical line. Therefore, the proposed system would be a promising solution and cost effective for the next generation optical access networks, such as Fiber-to-the-Home (FTTH).

In the same year, S. Spolitis et al. in [18] proposed high speed dense 8-channel bidirectional WDM-PON access system where spectrally-uniform Amplified spontaneous emission (ASE) source is shared among multiple users for realization of downstream transmission. Upstream transmission is realized by using conventional laser based solution. Here an extra optical amplifier is used for the suppression of intensity noise and cross distortion compression. With these modification a reduction in the BER is observed and has widely opening of eyes.

In 2015, Osayd M. Kharraz et al. in [19] demonstrated a method for the enhancement of optical SNR (OSNR) and the generation of the ultra-narrow pre spectrum sliced channel fibers using Four Wave mixing (FWM) which is highly nonlinear in nature. Author have made an experimental setup which has a narrow band filter module configuration and consisted of FBG, band pass filter s, and blocker filter. This module is used to create the pre spectrum sliced probe channel. This pre spectrum sliced probe and amplified pump channel are connected together to the polarization controller to provide the maximum FWM efficiency. The system consist the another module called as aforementioned filter module and this module has the capability to generate an ultra-narrow line width pre spectrum sliced channel. The spectrum of the ultra-narrow sliced channel using FWM is generated.

In the same year, Dipen Manandhar et al. in [20] gives a spectrum slicing WDM passive optical network with 25GHz each. the channel spacing between the PON is 25GHz and the channels are separated into even and odd sliced spectrum using a pair of 50GHz Array waveguide (AWG).experiment has been performed which uses two array wave guides (AWGs), AWG1 is for the even channels and AWG2 is for the odd channels and hence the transmission of upstream and downstream data will takes place. After transmission it will be DE multiplexed using a pair of AWGs and the conclusion has been made that the proposed spectrum sliced WDM-PON using 25GHz AWG for both upstream and downstream has better BER performance.

In the same year, Muthana. Y. Aldouri and Luma. W. Jameel in [21] proposed slicing technique for 32 channels and also they proposed architecture which has three sections transmitter section fiber optics section and receiver. Transmitter section comprises of broadband light source and modulator and receiver section consist of demodulator as the important component. For demodulation PIN diode is used and subtraction detection technique is employed.

III. CONCLUSION

This paper presents a comparative study on various methods of spectrum slicing techniques for the last few years. Different slicing methods are explained by using WDM and AWG. The crosstalk produced in conventional methods can be eliminated by using spectrum slicing technique. The bit error rate (BER) and signal to noise ratio (SNR) introduced by spectrum slicing network was analyzed and compared with other systems. Most methods used laser light sources are used as the light source for spectrum slicing optical communication. Usage of more energy efficient light sources results in low power consumption of the system. Also this spectrum slicing technique can be incorporated in any optical system where low power consumption is preferred.

REFERENCES

[1] Jung, D.K.; Shin, S.K.; Lee, C.-H.; Chung, Y.C., "Wavelength-division-multiplexed passive optical network based on spectrum-slicing techniques," in Photonics Technology Letters, IEEE , vol.10, no.9, pp.1334-1336, Sept. 1998

[2] Jang, Y.S.; Lee, Ch.; Chung, Y.C., "Effects of crosstalk in WDM systems using spectrum-sliced light sources," in Photonics Technology Letters, IEEE , vol.11, no.6, pp.715-717, June 1999.

[3] M. Zhao, G. Morthier, and R. Baets, “Analysis and optimization of intensity noise reduction in spectrum-sliced WDM systems using a saturated semiconductor optical amplifier,” IEEE Photon. Technol. Lett., vol. 14, no. 3, pp. 390–392, Mar. 2002.

[4] A. D. McCoy, B. C. Thomsen, M. Ibsen, and D. J. Richardson, “Filtering effects in a spectrum-sliced WDM system using SOA based noise reduction,” IEEE Photon. Technol. Lett., vol. 16, no. 2, pp. 680–682, Feb. 2004.

[5] McCoy, A.D.; Horak, P.; Thomsen, B.C.; Ibsen, M.; Mokhtar, M.R.; Richardson, D.J., "Improving signal quality in a spectrum-sliced WDM system using SOA-based noise reduction," in Photonics Technology Letters, IEEE , vol.17, no.1, pp.241-243, Jan. 2005.

[6] David Forsyth and Michael Connelly, “Spectrum-sliced wavelength conversion using Four-wave mixing from a semiconductor optical amplifier”,optical society of America 2005.

[7] Leeson M. S., Luo B. and Robinson A. J. “Spectral slicing for data communications,” Proceedings Symposium IEEE/LEOS Benelux Chapter, Eindhoven, pp. 165-168, 2006.

[8] Francesco Vacondio, Walid Mathlouthi, Pascal Lemieux, Leslie Ann Rusch, “SOA-Based noise suppression in spectrum-sliced PONs:impact of bit-rate and SOA gain recovery time”, proceedings of the seventh IASTED international conferences, 2007.

[9] S B Sun and M S Leeson,”Spectrum –sliced WDM and Incoherent optical CDMA: A performance comparison”, ISBN, 2008.

[10] Ghazisaeidi, A.; Vacondio, F.; Bononi, A.; Rusch, L.A., "SOA Intensity Noise Suppression in Spectrum Sliced Systems: A Multicanonical Monte Carlo Simulator of Extremely Low BER," in Lightwave Technology, Journal of, vol.27, no.14, pp.2667-2677, July15, 2009

[11] Aldouri, M.Y.; Aljunid, S.A.; Anuar, M.S.; Fadhil, H.A.; Ahmed, N., "One EDFA loop in 16 channels spectrum slicing WDM for FTTH access network," in Photonics (ICP), 2010 International Conference on , vol., no., pp.1-5, 5-7 July 2010

[12] Bobrovs, V.; Spolitis, S.; Ivanovs, G.; Gavars, P., "Performance improvement of high speed spectrum-sliced dense WDM-PON system," in Telecommunications (BIHTEL), 2012 IX International Symposium on, vol., no., pp.1-6, 25-27 Oct. 2012

[13] Junita, M.N.; Aljunid, S.A.; Anuar, M.S.; Arief, A.R.; Rahim, R.A.; Ahmad, R.B.; Saad, N.M., "Hybrid subcarrier multiplexing Wavelength Division Multiplexing using laser and LED spectral slicing architecture," in Industrial Electronics and Applications (ISIEA), 2012 IEEE Symposium on , vol., no., pp.34-38, 23-26 Sept. 2012

[14] Spolitis, S.; Bobrovs, V.; Ivanovs, G., "Reach Improvement of Spectrum-Sliced Dense WDM-PON System," in Broadband, Wireless Computing, Communication and Applications (BWCCA), 2012 Seventh International Conference on , vol., no., pp.296-301, 12-14 Nov. 2012

[15] Hoon Kim, "10-Gb/s/channel WDM PON using ultra-narrow spectrum-sliced incoherent light source," in Information, Communications and Signal Processing (ICICS) 2013 9th International Conference on , vol., no., pp.1-3, 10-13 Dec. 2013

[16] Han Hyub Lee, Seung-Hyun Cho, Jie Hyun Lee, Jong Hyun Lee, Sang Soo Lee, Demonstration of performance enhanced pre-spectrum sliced seed light for low-cost seeded WDM–PON architecture, Optical Fiber Technology, Volume 19, Issue 2, March 2013, Pages 126-131

[17] Abdel Hakeim M. Husein, Fady I. El Nahal, Optimal design of 32 channels spectrum slicing WDM for optical fiber access network system, Optik - International Journal for Light and Electron Optics, Volume 125, Issue 18, September 2014, Pages 5141-5143

[18] Spolitis, S.; Olonkins, S.; Porins, J., "Realization of dense bidirectional spectrum sliced WDM-PON access system," in Communication Systems, Networks & Digital Signal Processing (CSNDSP), 2014 9th International Symposium on , vol., no., pp.552-557, 23-25 July 2014

[19] Osayd M. Kharraz, Harith Ahmad, Abu Bakar B. Mohammad, David I. Forsyth, Mohamad Dernaika, Sulaiman W. Harun, Performance enhancement of pre-spectrum slicing technique for wavelength conversion,

Optics Communications, Volume 350, 1 September 2015, Pages 154-159

[20] Manandhar, D.; Hyung Hwan Kim; Chul Han Kim; Jae Seung Lee, "25-GHz Spaced Spectrum-Sliced WDM PON Using 50-GHz AWGs," in Photonics Technology Letters, IEEE , vol.27, no.13, pp.1383-1386, July1, 1 2015

[21] Muthana Y Aldouri and Luma W Jameel,"32 channels slicing with AM modulator using LED source", international journal of Electronics communication and computer engineering, volume 6, issue 6, 2015.