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Analysis of Different Wavelength Injection Techniques in Bidirectional Wavelength Division Multiplexed Passive Optical Networks

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Abstract

In this paper, a combination of different wavelength injection techniques is demonstrated in a bidirectional WDM PON's implementation using arrayed waveguide grating. Wavelength reusable ONU's are provided with fiber bragg grating at particular wavelength, so that it reflects particular wavelength and transmits the remaining power, which is re-modulated as upstream by LiNbO3 modulator. Self seeding based ONU's are provided with reflective semiconductor optical amplifier, so that it not only function as amplifier, but also as a modulator for upstream generation(no need of local sources). Externally wavelength injected ONU's are provided with local source for upstream generation. The integration of all three wavelength injection techniques makes a true next generation PON technologies. The performance of implemented system has been analyzed on the basis of Min-log of BER versus OSNR, Min-log of BER versus received power. The performance of wavelength reusable based ONU's are close to externally injected ONU's performance in both downstream and upstream, so that it can be used in place of externally wavelength injected with link-length trade-off. Self-seeding based ONU's performance is close to externally wavelength injected ONU's performance below 50Km link-length in both downstream and upstream, so that it can be used in place of externally wavelength injected with upstream data rate trade-off.

Keywords: Arrayed Waveguide-Grating (AWG), Fiber Bragg Grating (FBG), Passive Optical Network (PON), Reflective Semiconductor Optical Amplifier (RSOA), Wavelength Division Multiplexing (WDM)

1. Introduction

Access evolution from xDSL to FTTX – xDSL and cable modem technology made improvements in bandwidth capacity but have physical limitations to open the capacity bottleneck that exists in subscriber access networks, which cover the "first mile" areas and serve numerous residential and small business users. Thus, xDSL and cable modem technology are being replaced by optical network technologies, like fiber-to-the-X (or FTTX,

where X can mean the home, curb, cabinet, or building). FTTX technologies have been envisioned as a preferred solution because of their potential to provide high data rates and low energy per bit to subscribers, and passive optical networks (PONs) have been widely considered as a promising technology for implementing various FTTX solutions¹.

A PON basically comprises an optical line terminal (OLT) at the Central Office, an optical fiber, an optical distribution node (ODD), and multiple optical network

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units (ONUs) close to users premises. The OLT assigns the downlink wavelength, modulates the downstream data on this wavelength, and then propagates it into the optical fiber. The ODD (or remote node (RN)) de-multiplexes the downstream optical signal which is received from the optical fiber to multiple ONUs and also multiplexes the upstream traffic from the ONUs to the optical fiber. The ONUs receive the downstream traffic from the RN and generate the upstream traffic to the optical link on the uplink wavelength².A bidirectional WDM-PON architecture using reflective filter and cyclic AWG is demonstrated in³. Korea-Telecom (KT) employed WDM-PON with wavelength reuse concept in the fiber to curb network and provides 1.25 Gbps data rate with sixteen WDM channels each. In order to support the triple play services, KT employed the colorless gigabit hybrid PON system with WDM/TDM⁴. RSOA-based Optical Network Units for WDM-PON is demonstrated in 5. A local laser source at ONU side is another choice of architecture for implementing PON technologies. The combination of three architectures mentioned above is truly a solution for next generation PON technologies.

Requirements of a next generation PON technologies is with the ever-increasing requirements of bandwidth, a next generation optical access (NGOA) network with a higher bandwidth per customer is a natural path forward⁶. The NGOA solution should also allow seamless migration of customers and should coexist with present networks to protect the investment of network operators. In addition, network operators require many additional attributes to optimize their investments in the NGOA solution.

2. Different Wavelength Injection **WDM-PON Structures**

2.1 Proposed Structures

There are three types of wavelength injections namely wavelength reuse, self seeding and external wavelength injection are discussed in⁷. The wavelength reuse is based on reusing the same wavelength which was used for transmission of downstream data will also be used for upstream data which is generated by using fiber bragg grating at ONU side, and eliminates the need of local source. The self-seeding is employed based on using the reflected power from reflective semiconductor optical amplifier for upstream data generation at ONU side, which rules out the necessity of local source. Finally,

external injection comes under normal case where a local source will be placed at ONU side. Figures 1, 2 & 3 shows the proposed WDM-PON structures using reflective-filter (FBG), reflective semiconductor optical amplifier and local source (EXT) respectively. The integration of these wavelength injection techniques makes the next generation PON structure as shown in Figure 4.

In the wavelength-reuse injection technique based on fiber bragg grating, a WDM transmitter is used to generate the downstream signals at the central office side. The generated downstream signals were multiplexed by bidirectional arrayed waveguide grating and fed to bidirectional circulator. The output signal from circulator is fed to a bidirectional single mode fiber and then to bidirectional arrayed waveguide grating which serves as a de-multiplexer for downstream signals. The de-multiplexed downstream signals are given to fiber bragg grating which reflects the signal of specific wavelength and transmits the data with certain power. Finally the reflected signal is detected by PIN photodiode and the BER is analyzed. The transmission output of fiber bragg grating is given as carrier input of LiNbO3 Mach-Zehnder modulator which modulates the data generated by using PRBS(pseudo random binary sequence). The upstream signals is given to same bidirectional arrayed wave grating which is used for de-multiplexing of downstream signals earlier, will now acts as multiplexer for upstream signals. The multiplexed signal is fed to the same bidirectional single mode fiber which is used as downstream channel. After propagating through fiber, signal is fed to bidirectional circulator and from circulator, it is fed to bidirectional arrayed wave grating which is already used as multiplexer for downstream signals earlier, is now used for de-multiplexing of upstream signals. The outputs of de-multiplexed upstream signals are detected by PIN photodiodes and finally BER is analyzed. The downstream signals are also given to reflective semiconductor optical amplifier for the self-seeding wavelength injection technique. The reflective semiconductor optical amplifier will act as both amplifier and modulator, where one of its input will be given from PRBS (Pseudo Random Binary Sequence) generator and re-modulates the signal as upstream signal. The demodulation of downstream signal is performed by PIN photodiode and the BER is analyzed. The upstream detection is performed by the same procedure as in wavelength-reuse injection technique i.e., it passes through arrayed wave grating and then to bi-directional single mode fiber and finally to circulator as shown in Figure 2. The downstream signals is also given to ONU's with local source and detection arrangement, so that the upstream is generated by external source (EXT) and same mechanism mentioned above is followed for upstream detection. Therefore it is evident from the above description that the integration of all these three wavelength injection types are truly considered as next generation PON technology.

2.2 Fiber Bragg Grating

The fiber bragg grating is a dispersed kind of bragg reflector built in a short section of optical fiber that reflects specific wavelengths of light and transmits all other wavelengths⁸. The above phenomenon can be achieved by creating periodic disparity in refractive Index of core region of optical fiber, which creates a wavelength

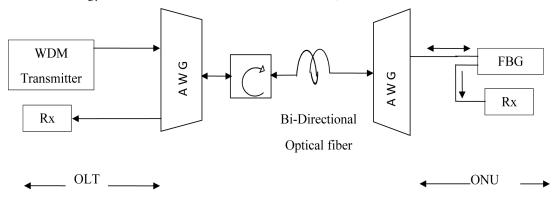


Figure 1. Wavelength reuse based PON.

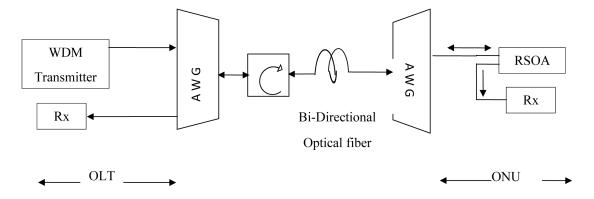


Figure 2. Self-seeding based PON.

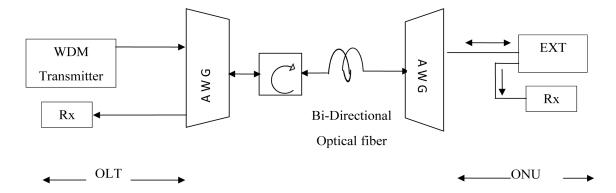


Figure 3. External Wavelength Injection based PON.

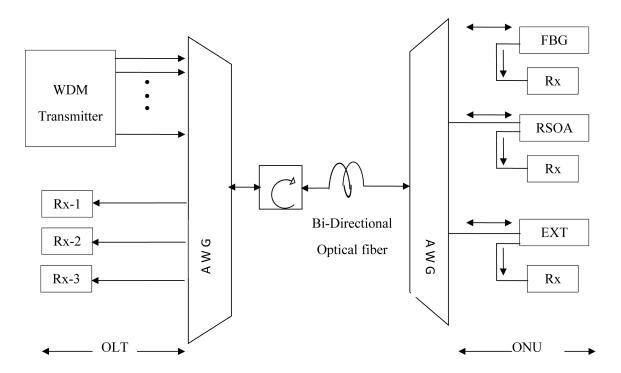


Figure 4. Next generation PON technologies.

particular dielectric mirror or reflector. To block certain wavelengths and transmits remaining wavelengths is similar to operation of optical filter, thus fiber bragg grating can be called as reflective filter. The fundamental principle involved in operation of fiber bragg grating is fresnel reflections, because of different refractive indices of media, light travelling between them is involved in both refraction and reflection at the interface. Over a defined wavelength, the refractive index is varied, the reflected wavelength (λ_{R}) is known as bragg wavelength, given by following formula.

$$\lambda B = 2^* ne^* \Lambda$$

where the grating period is denoted by Λ and the effective refractive index is denoted by n_a.

The velocity of light in vacuum is compared with velocity of propagating light quantifies the role of effective refractive index. The value of n is depends on the mode in which it is propagating and also on the wavelength, because of this, it is also known as modal index. The fiber bragg grating is assigned with specific wavelength, which is allocated for each user. The fiber bragg grating reflects the specific wavelength which is assigned and transmits the remaining power, which can be used as carrier power for modulation of upstream signal.

2.3 Arrayed Waveguide Grating

With the capability of de-multiplexing a large number of optical signals (carrying information at various wavelengths) with low loss switching, made the arrayed waveguide grating popular in field of optical communications. The further applications of AWG's are integration with systems like optical add-drop multiplexers (OADM's) and Fiber to the X(home, office..) and also with CWDM systems, where the transmitting optical signals are less.

The arrayed waveguides and two couplers forms a AWG, based on the substrate9. The multiple wavelengths given to input coupler through input waveguides, then the light propagates through the arrayed waveguides to output coupler. The cut-off wavelength λ_c of de-multiplexer defined the length of waveguides based on optical path difference between adjacent waveguides. The particular wavelength comes out of any one of the N output waveguides based on the length of arrayed waveguides that causes interference and diffraction when light mixes in the output coupler. The both multiplexer and de-multiplexer can be performed by arrayed waveguide gratings. A cyclic AWG is one the output of N port is reappear at port 1 i.e cyclic behaviour. It is possible by keeping the free spectral range is equal to N times the channel spacing with the AWG'S of N inputs and N outputs. Such a device is shown in Figure 5.

2.4 Reflective Semiconductor Optical Amplifier

The RSOA can be used as an amplifier¹⁰. This gives additional gain enabling the possibility of avoiding the use of an erbium doped fiber amplifier (EDFA) in the system. It is not as shown, however, due to its properties it allows higher gain than the SOA and its gain nonlinearity is also interesting for wavelength conversion. Reflective semiconductor optical amplifier offers highly optimized performance for WDM PON applications. It is capable of delivering 20 dB of gain, the semiconductor optical amplifier (SOA) can demodulated at rates up to 1.5 Gb/s to provide wavelength-agile optical data transmission facilities for clients in (FTTH/FTTP) access network architectures - without the expense of a tunable wavelength source. The RSOA is a cost-effective since it performs the functions of not only modulator (no need for local laser source), but also amplifier. It considers the possibility of sensing the differences in voltage produced at the bias electrode of the single-section SOA. The value of the injection current in the RSOA is considered as an input signal allowing the modulation of the optical signal by the SOA.

3. Simulation and Results

The simulation is done by optiwave optisystem¹³ (evaluation version)¹¹. The simulation setup is provided with three channels with different data rates to serve triple-play services. At central office, for the wavelength reuse (fiber bragg grating) based ONU's it is provided with downstream rate of 7.5Gb/s and upstream rate of 3.75Gb/s. With a power of 0 dBm, the BER achieved for downstream is $2.52*e^{-10}$ at the length of 110km and BER of $3.17*e^{-09}$ is

achieved for upstream at the length of 60km. To reach further, in case of upstream, a EDFA placed before receiver module of upstream detection serves the purpose . For the wavelength reuse (fiber bragg grating) based ONU's, another set of data rates are used for simulation ,downstream rate of 5Gb/s and upstream rate of 2.5Gb/s. With a power of 0dBm, the BER achieved for downstream is $4.27*e^{-10}$ at the length of 115km and BER of $9.46*e^{-10}$ is achieved for upstream at the length of 65km.

For the self-seeding(reflective semiconductor optical amplifier) based ONU's it is provided with downstream rate of 10Gb/s and upstream rate of 1Gb/s. With a power of 0dBm, the BER achieved for downstream is $1.25*e^{-15}$ at the length of 75km and BER of 3.25*e⁻⁰⁹ is achieved for upstream at the length of 52km. For the external injection based ONU's it is provided with downstream rate of 10Gb/s and upstream rate of 10Gb/s. With a power of 0 dBm, the BER achieved for downstream is 1.25*e-¹⁵ and BER of 3.05*e⁻¹⁵ is achieved for upstream at the length of 75km. Another set of data rates are with downstream rate of 7.5Gb/s, upstream rate of 7.5Gb/s and power of 0 dBm, the BER achieved for downstream is $1.84*e^{-15}$ and BER of $4.29*e^{-15}$ is achieved for upstream at the length of 129km. The performance of implemented system has been analyzed on the basis of min-log of BER versus OSNR (dB), min-log of BER versus received power for both upstream and downstream. The min-log of BER versus received power (dBm) for downstream and upstream in all types of wavelength injection types are shown in Figure 6 and Figure 7.As received power increases, the BER increases gradually with respect to received power in both the cases of upstream and downstream. The min-log of BER versus OSNR (dB) for downstream and upstream in all types of wavelength injection types are shown in Figure 8, Figure 9 and Figure 10. As OSNR increases, the BER increases gradually with respect to OSNR in both the cases of upstream and downstream.

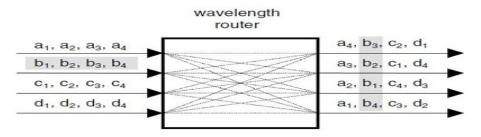


Figure 5. Schematic diagram illustrating the operation of a wavelength router.

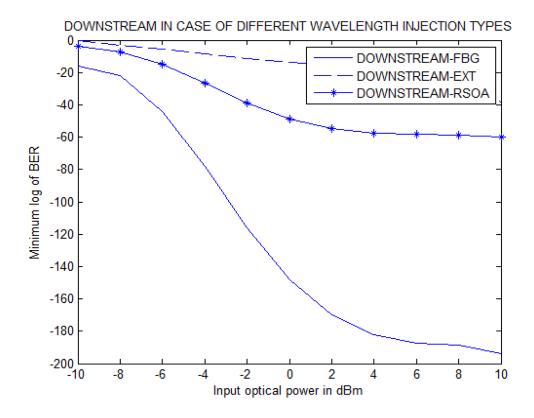


Figure 6. Min-Log of BER versus Received Optical Power (dBm) in case of downstream.

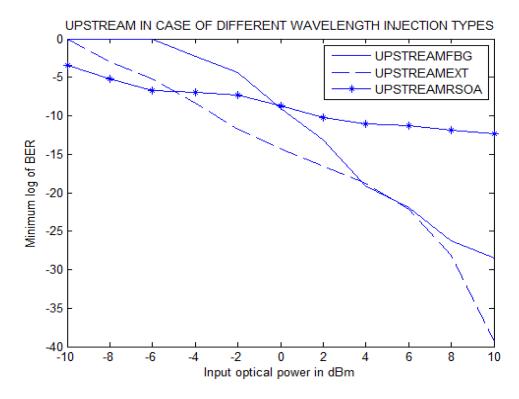


Figure 7. Min-Log of BER versus Received Optical Power (dBm) in case of upstream.

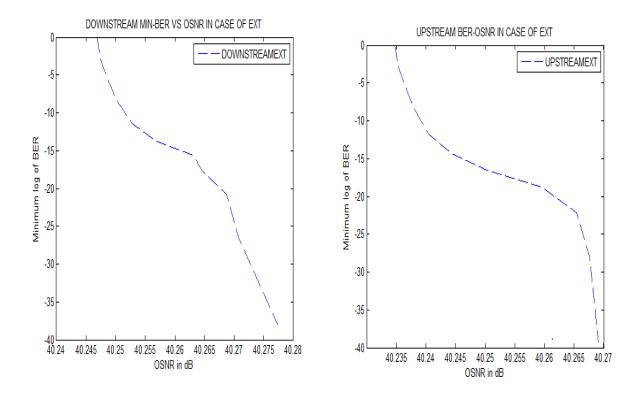


Figure 8. Min-Log of BER versus OSNR(dB) in case of External Injection.

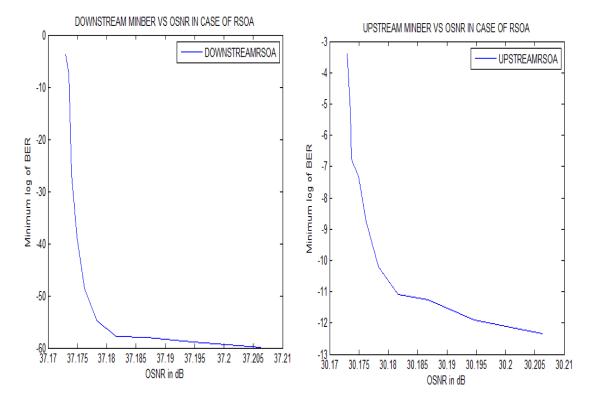


Figure 9. Min Log of BER versus OSNR(dB) in case of Self-seeding.

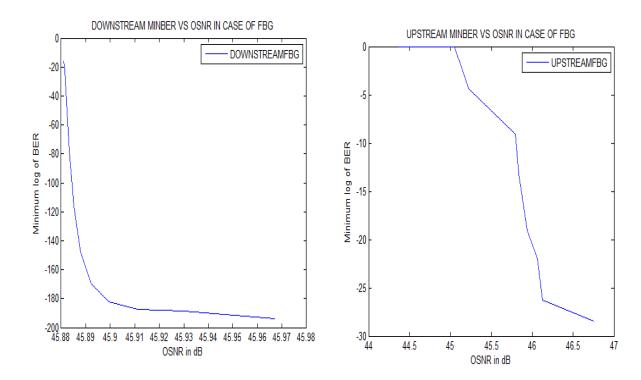


Figure 10. Min Log of BER versus OSNR(dB) in case of Wavelength reuse.

4. Conclusion

The next generation PON Technologies is truly the solution for future version of optical broadband access and FTTH services. The combination of different wavelength injection techniques like fiber bragg grating based ONU's, reflective semiconductor optical amplifiers based ONU's and external injection based ONU's is demonstrated in case of bidirectional WDM PON's implemented using arrayed waveguide gratings. The integration of these three techniques gives the ultimate solution for future data access requirement. The implemented system offers good BER performance and the system link length can be increased further for upstream performance with the use of EDFA before receiver module. The performance of wavelength reusable based ONU's are close to externally wavelength injected ONU's performance in both downstream and upstream, so that it can be used in place of externally wavelength injected with link-length trade-off. Self-seeding based ONU's performance is close to externally wavelength injected ONU's performance below 50Km link-length in both downstream and upstream,

so that it can be used in place of externally wavelength injected with upstream data rate trade-off. From the results mentioned above, based on data rate requirement, the particular PON structure is implemented on needs of urban, sub-urban and rural usage.

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