Analysis of OOK Upstream Signal Remodulation for Different Data Rates in WDM PON Network

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***Abstract*—A bidirectional wavelength division multiplexed passive optical network (PON) has been proposed in which downstream differential phase shift keying (DPSK) signal is used for upstream on off keying (OOK) signal remodulation. This proposed passive optical network architecture is capable to support the high bandwidth requirements for present applications such as video conferencing, online gaming, telemedicine etc. Due to use of wavelength division multiplexing, insertion losses of the proposed architecture are also reduced. Due to low insertion losses, WDM PON can work with low input powers. In this architecture, authors use 10Gbps DPSK signal for 1.25, 2.5 and 5Gbps OOK signal remodulation. Error free operation is achieved for 20km fiber without any dispersion compensation with low power penalty for downstream and negligible for upstream. Impact of different - different data rates for OOK upstream signal remodulation has been analyzed in terms of bit error rate and Q factor for received power penalty.**

***Index Terms*—wavelength division multiplexing (WDM), passive optical network (PON), on off keying (OOK), differential phase shift keying (DPSK), optical networking unit (ONU), arrayed waveguide grating (AWG)**

I. Introduction

Most important decision for any business is to minimize the cost of developing system while maximizing output from it. Thus, a service provider has to make a balance between minimizing the system cost and maximizing the bandwidth. The passive optical network is just one of the network access technologies that are used by the service providers. PON is also known as fiber access technology since it uses the optical fiber to serve high speed network. The other access network technologies are digital subscriber line (DSL), wireless optical broadband access network (WOBAN) and long reach PON (LR-PON). In USA, DSL is the most dominant access technology; due to the use of multiple copper cables in same bundle this technology suffers from electromagnetic interference or cross talk [1].

Passive optical networks are referred to as network access technology. Because of almost unlimited bandwidth, PONs are considered as a promising solution to support next generation FTTX applications such as high definition television (HDTV), video conferencing, online games, and video on demand services. This fiber based access technology also provides immunity to electromagnetic interference, crosstalk, and data security. Now a day’s passive optical network are also used for virtual applications such as telemedicine and virtual classes etc. to reduce manpower, network infrastructure and hardware requirements [2].

Besides the high speed, passive optical networks are also able to provide attractive features like protocol transparency, channel independency, network security and flexibility to upgrade network according to the customers need and applications. To provide the more flexible and ubiquitous networks wireless front end connectivity is used with optical backhaul and this technology is called wireless optical broadband access network access technology [3].

A serious problem in passive optical access network is to use a wavelength specific light source for each optical networking unit which is not cost effective. To overcome the requirement of costly wavelength specific light source for each optical networking unit (ONU), a centralized light source is used at central office to reduce the cost and complexity of the system. In [4], authors proposed a wavelength division multiplexed passive optical network in which they use a centralized light source to transmit downstream as well as broadcasted signal.

Broadcasting can be done by several techniques. In one approach, the separated light source is used for transmitting broadcasted signal, but the use of additional light source is not a cost effective solution [5]. Wavelength division multiplexing can be used to broadcast the signal and to separate the different wavelength signal, array waveguide grating is used to separate different wavelength signals. Another cost effective approach is to use the time division multiplexing technique, in TDM multiplexing power splitter is used to broadcast the signals [6].

Broadcasting capabilities of any network increases the transmission coverage and total number of supported customers without increasing the light sources. In centralized light source technique, part of the downstream signal is used for upstream data remodulation [4].

There are some limitations of time division multiplexing. For higher splitting ratios of power splitter, insertion losses increase. The insertion losses of power splitter is given by $3.5\log_2(n)$, where n is the number of

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output port of power splitter. To minimize the insertion loss, wavelength division multiplexing is used since it uses array waveguide grating (AWG). And the insertion losses of AWG is fixed and given by approximate value of 5dB [7].

According to required bandwidth, applications one can choose whether to use TDM or WDM. It actually depends on how many number of interfaces are required. To reduce the number of interfaces and insertion losses WDM is used. Table I indicates the power budget required for different multiplexing techniques in which insertion losses of power splitter is given by $3.5\log_2(n)$ and losses of AWG is fixed 5dB. While calculating these values attenuation losses of optical fiber are also considered and having value 0.2dB/km [7].

TABLE I. REQUIRED POWER BUDGET

Length(km)	Output ports of splitter	Power budget for Splitter(dB)	Power budget for AWG(dB)
10	8	12.5	7
10	16	16	7
10	32	19.5	7
10	64	23	7
20	8	14.5	9
20	16	18	9
20	32	21.5	9
20	64	25	9

In past few years, several remodulation schemes have been proposed. Few downstream and upstream combinations are: downstream differential phase shift keying (DPSK) signals and upstream on off keying (OOK) signals [8]; downstream frequency shift keying (FSK) signal and upstream on off keying (OOK) signals have been performed experimentally, 2.5Gbps downstream orthogonal frequency shift keying (OFSK) data and 2.5Gbps upstream OOK data is used to remodulate the upstream signal at constant intensity [9].

Downstream dark return to zero (DRZ) signals and upstream on off keying (OOK) signals has been given in [10]. Downstream dark return to zero signals has been used for downstream transmission and on off keying signals for upstream transmission for 10Gbps both sides. DRZ orthogonal modulation gives high extension ratio (ER) that gives improved margin at receiver than a conventional modulation [11].

Downstream on off keying (OOK) signals and upstream on off keying (OOK) signals; downstream differential phase shift keying (DPSK) signals and upstream differential phase shift keying (DPSK) signals are also possible combinations for downstream and upstream transmission [12].

Authors in [13] proposed a signal remodulation scheme in which they use a 10Gbps DPSK downstream signal for upstream 2.5Gbps OOK signal remodulation by using reflective semiconductor optical amplifier (RSOA), and received error free signals for 20km fiber without dispersion compensation. In our paper, the results of BER and Q factor for 1.25, 2.5 and 5Gbps OOK upstream signal remodulation have been compared and power penalty due to different data rates is observed.

For downstream transmission DPSK modulation format have several advantages over the OOK modulation format, for example single LiNbO3 crystal optical phase modulator used for DPSK modulation costs less than Mach-Zehnder Intensity modulator used in OOK modulation. DPSK modulation format have constant intensity nature at the output and hence keep high extension ratio (ER) and able to tolerate more fiber nonlinear impairments and chromatic dispersion [14], [15]. To utilize the above advantages of DPSK, this paper uses the combination of OOK modulation with DPSK for downstream transmission.

Since passive optical network uses all passive components such as such as Optical Line Terminal (OLT), Optical Networking Unit (ONU), Array Waveguide Grating (AWG) and Power Splitter (PS). PON consumes very less power. PONs are supposed to provide much wider coverage with larger capacity [16]. This energy efficiency is another advantage of passive optical network with cost effectiveness [17].

One main disadvantage of passive optical network is less ubiquitous in nature since PON provides the wired optical access. To mitigate this problem wireless optical broadband access network (WOBAN) is proposed in [18], authors use optical backhaul to provide high bandwidth and wireless at front end to provide flexible communication network. For optical backhaul, passive optical networks and fiber to the home networks are used while WiFi and WiMAX services are used to provide wireless front end connectivity [19].

II. SIMULATION SETUP

To analyze the performance of different data rates for OOK upstream signal remodulation of our proposed PON structure, a simulation setup is designed with the help of optisystem 12 software. A simulation on 10Gbps DPSK downstream signals is used for 1.25, 2.5 and 5Gbps OOK upstream signal remodulation respectively. For generation of differential phase shift keying (DPSK) signal, Phase Modulator (PM) is used at central office (CO) or at optical line terminal (OLT). Central office consists of optical source, modulator, transmitter to send downstream signal and receiver to receive upstream signal.

Arrayed waveguide grating (AWG) multiplexes the different wavelength signals and passes to the optical circulator (OC). The received signal from the circulator is transmitted through a 20km optical fiber. To analyze the impact of 20km optical fiber on the performance of the proposed system, the results of B2B system is compared with 20km fiber system, these both systems are shown in Fig. 1.a and Fig. 1.b.

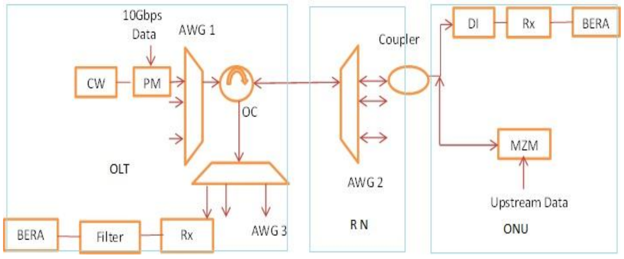

Figure 1.a. The WDM PON simulation architecture using OOK-DPSK downstream and OOK upstream signals for B2B. MZM: phase modulator, OC: optical coupler, AWG: arrayed waveguide grating, DI: delayed interferometer, BERA: bit error rate analyzer, RN: remote node

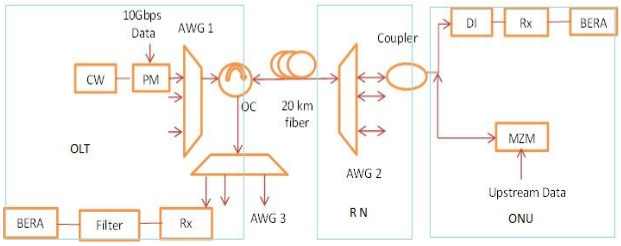

Figure 1.b. The WDM PON simulation architecture using OOK-DPSK downstream and OOK upstream signals for 20km fiber.

At remote node (RN), arrayed waveguide grating is used to demultiplex and separate the different wavelength signals; separated signals are then demodulated and detected at the optical networking unit. Before detection of the received signal, with the help of coupler this received signal is split in two parts.

One part of the signal is used for the downstream point to point transmission while another part of this signal is used for remodulation purpose which is later used for upstream transmission. At optical networking unit (ONU) there is demodulator, filter receiver to receive downstream signal and transmitter to transmit upstream signal, downstream signal is received and analyzed by bit error rate analyzer (BERA) which shows a clear reception of signal for 20km fiber as well as for back to back system without any dispersion compensation. Bit error rate (BER) of downstream signal is measured for back to back (B2B) and 20km fiber.

The single mode fiber has the attenuation coefficient of 0.2dB/km, dispersion parameter of 16.75ps/nm/km and dispersion slope of 0.075ps/nm2/km and have the effective area of 80 μm^2. Part of received downstream signal is reused for upstream transmission for this; downstream signal is re-modulated at 1.25, 2.5 and 5Gbps data rates.

These upstream signals are multiplexed by AWG 2 and transmitted through 20km fiber. Circulator transfer upstream data to AWG 3. This array waveguide grating demultiplexes this upstream signal. Analysis of this received upstream signal is done by another BERA at central office.

III. Results

Fig. 2 shows the graph between max Q factor and min log of BER, in which the quality factor of 6 is achieved at min log of BER of -9. As the launched power increases, both the quality factor and bit error rate improves. The measured power penalty for downstream DPSK transmission for 20km fiber is approximately 1.5dB as shown in Fig. 3, and for upstream signal it is approximately 0.6dB as given in Fig. 4.

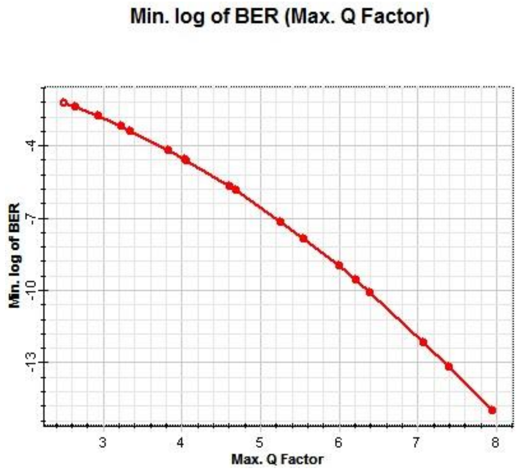

Figure 2. Plot between min log of BER v/s max Q factor for downstream transmission.

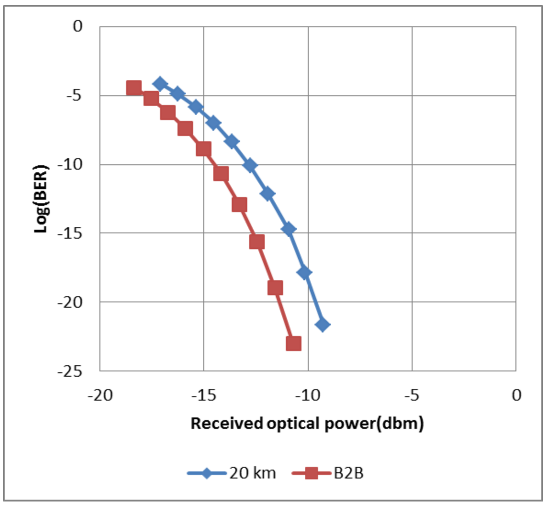

Figure 3. Plot between min log of BER v/s received optical power for downstream transmission.

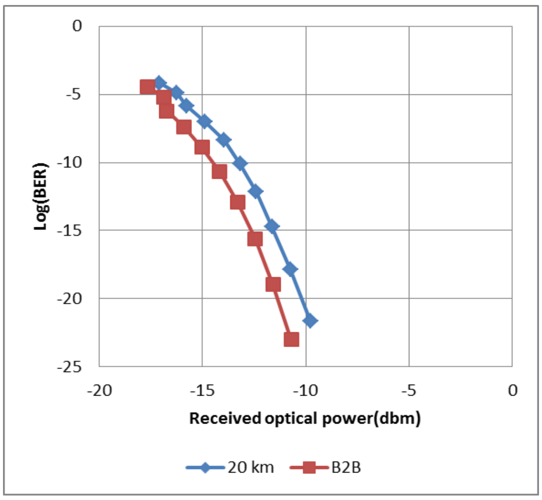

Figure 4. Plot between min log of BER v/s received optical power for upstream transmission.

Fig. 5 and Fig. 6 show the BER and Q factor analysis for upstream signal at varying data rates for 20km transmission respectively. Error free signals are received in all cases. As the launched power increases, the BER performance of the system improves.

1.25Gbps upstream signal on average requires 0.5dB less power than 5Gbps upstream signal in order to maintain same BER performance. For large input powers this difference becomes large due to nonlinear effects such as chromatic dispersion.

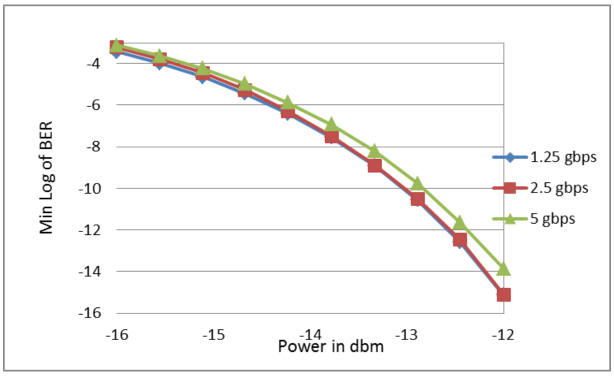

Figure 5. BER measurement for upstream transmission at different data rates

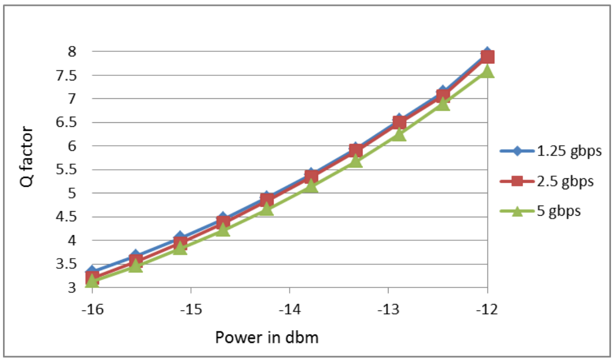

Figure 6. Q factor measurement for upstream transmission at different data rates

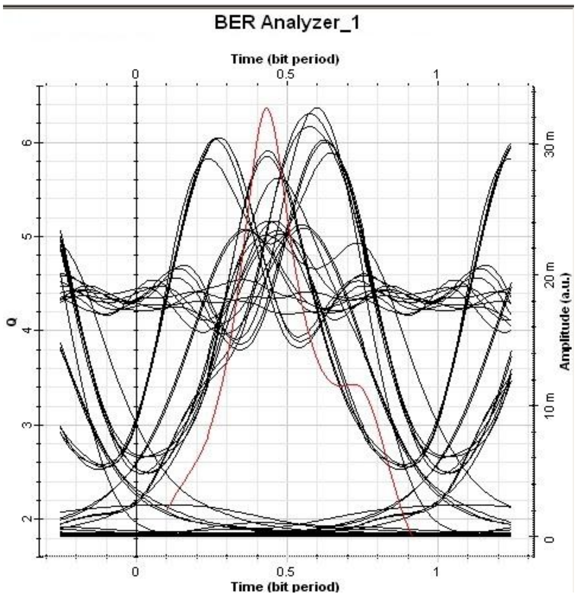

Figure 7. Measured eye diagram for downstream transmission for 20km fiber

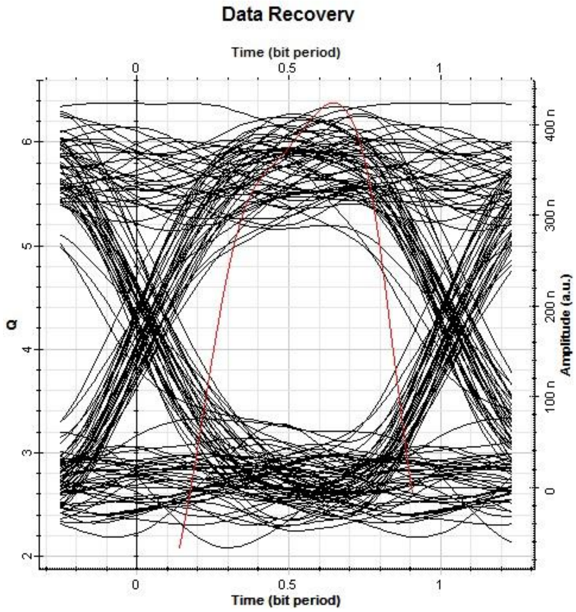

Figure 8. Measured eye diagram for upstream transmission for 20km fiber

In this paper, Eye diagrams are also observed for both downstream and upstream data transmission for 20km fiber as shown in Fig. 7 and Fig. 8 respectively. These figures show the clear Eye opening i.e. clear signal reception after 20km. Red curve in these eye diagrams indicates the Q factor curve which is higher than 6 in both cases to give satisfactory performance.

IV. Conclusions

We have simulated the bidirectional passive optical network using 10Gbps DPSK signal for 1.25, 2.5 and 5Gbps upstream OOK signal remodulation. Error free operation is achieved for 20km fiber without any dispersion compensation with approximately 1.5dB power penalty for downstream and 0.6 for upstream. Results also include the observation of variation in the BER and Q factor w.r.t. received optical power for different upstream data rates, which shows that there is some power penalty at high data rate signals.

On an average 1.25Gbps upstream signal requires 0.5dB less power than 5Gbps upstream signal in order to maintain same BER performance. For large input powers, due to nonlinear effects such as chromatic dispersion power penalty increases, Q factor and BER performance degrades.

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