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Research Article

Performance Evaluation and Optimization of Wavelength Division Multiplexing Passive Optical Networks

The promising solution for the next generation ofFiber-To-The-Home

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Abstract— **In this paper, a central power source architecture is applied to a realize power saving wavelength division multiplexing passive optical network (WDM-PON). Parametric study isevaluated to extend the transmission distance up to 60 and80 km. Optical launched power is optimized through the parametric study. A full duplex 16 optical channels WDM-PON system are experimentally simulated and analyzed. Successful transmission achieved maximum bit error rate (BER) of 10^{-13}.A return-to-zero differential phase shift keying (RZ-DPSK) modulation technique isutilized for downlink direction, and then the downlink signal is re-modulated for the uplink direction using intensity modulation technique of on-off keying (OOK) with a data rates of 5 and 1 Gbit/s per channel.**

Keywords-**FTTH; DPSK; OOK; WDM-PON**

I. INTRODUCTION

Optical fiber network commonly referred to a telecommunications network with optical fiber as the primary transmission medium which is designed in such a way that it makes full use of the unique attributes of optical fibers [1]. Passive optical networks (PONs), short reach optical networks free from optical amplification stages and powered elements, are widely considered by operators to provide connectivity over different access media to a large number of subscribers[2]. As the nameimplies, there are no active component between
the central office and the user premises.Active devices exist only in the central office and at user premises [3].

Through using one of multiplexing approach, Wavelength-division-multiplexing passive optical networks (WDM-PON) have become a promising solution for the next generation of FTTH architecture because of its almost unlimited bandwidth, security, and protocol transparency[4]. WDM-PON offers much higher transmission capacity and longer transmission distance than current PONs using separate wavelengths for each end unit. Nonlinearities and dispersion effects may affect a performance of transmission system and certain modulation formats can improve a quality of signal so the influence of current modulation formats on the performance of WDM-PON is tested[5, 6].

Researches designed and evaluated various WDM-PON architectures to meet the rapid growth in bandwidth demand combined with remarkable performance (i.e. low power consumption, readability, low cost, low complexity and low BER). O. Akanbi, in [7]designed and evaluated a bidirectional WDM-PON that uses single optical carrier suppression and separation (OCSS) technique to generate two 25 GHz spaced wavelength channels. Single distributed feedback (DFB) laser with arrayed waveguide grating (AWG) is used in the OLT. Also AWG was used before ONU to allow 16 dense wavelength division multiplexing (DWDM) channel operation at 10 Gbit/s channel transmission over 20 km.

Jing HUANG, in [8], proposed a WDM-PON with 10 Gbit/s per channel and non-return-to-zero differential-phase-shift-keyed (NRZ-DPSK) in downstream. A 10 Gbit/s OOK upstream based on SOAs. System was evaluated over 20 km distance and achieved 10^{-9} BER operation.

In [9] advantages of WDM-PON discussed earlier together with DPSK merits were combined to achieve low power and cost system. A 4-channels 10 Gbit/s operation with DPSK modulation in downstream and OOK in upstream is evaluated. A 60 GHz channel spacing was employed, transmission over 25 km was established and a BER of 10^{-9} is achieved with low power penalty.

In this work the transmission distance of a central power source architecture is expanded to 60 and 80 km with 16 optical channel. This is done using

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parametric study to choose the optimum suitable optical launched power. Full duplex link operation with5 and 1Gbit/s is achieved with maximum BER of 10^{-13}.

II. WDM-PON SYSTEM SCHEME

A. Introduction

Figure 1 shows the WDM-PON proposed system. Thegenerated downstream RZ-DPSK are multiplexedsignal to be transmitted over a standard single-mode fiber (SMF). At the other end, a demultiplexer (DeMUX) is used todemultiplex the downstream signals and send them to respectiveONU. At each ONU, after a power splitter (PS), the halfof the downstream phase encoded signal is re-modulated with the same data rate (1 or 5 Gbit/s) using an intensity modulation technique(i.e.,OOK) to be transmitted back to the OLT.

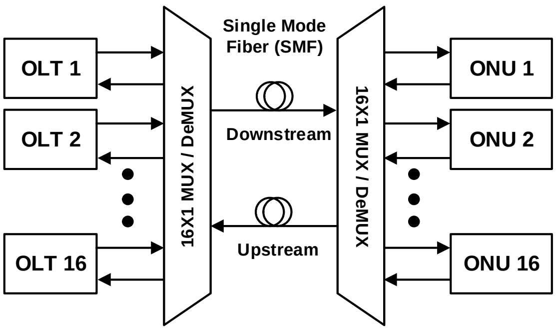

Figure 1. WDM-PON proposed system

Table I represents the operating parameters applied to the proposed system. Parametric study will optimize the optical launched power later in section III.

TABLE I. WDM-PON SYSTEM OPERATING PARAMETERS

Parameter	Value	Unit
Bit rate upstream	1 to 5	Gbit/s
Bit rate downstream	1 to 5	Gbit/s
Distance[a]	60 to 80	km
First Channel[b]	193.1	THz
Channel Spacing[b]	50	GHz
Number of Channel	16	N/A
Optcial Bandwidth	25	GHz
Sequence Length	256	Bits

a. Distance > 20 km, System categorized as highly scalable new generation PON[10].

b. Channel spacing and first channel are match nominal central frequencies for WDM systems [11].

B. Downstream Transmission Process

To generate the optical signal a continuous wave (CW) laser source NRZ pattern generator are supplied to single drive Mach-Zehnder Modulator (MZM). The duobinary precoder (composed of an Exclusive-OR gate with a delayed feedback path) is used to enable the generation of the electrical DPSK signal prior to its application to MZM1. Previous stage results in generating optical DPSK as shown in Fig. 3. Then optical DPSK is applied to MZM2 (pulse carver) that cuts out the amplitude modulation free center portions of the bits only, and thus largely eliminates any residual dips [12]. Figure 2 shows the optical RZ-DPSK transmitter stages in each OLT.

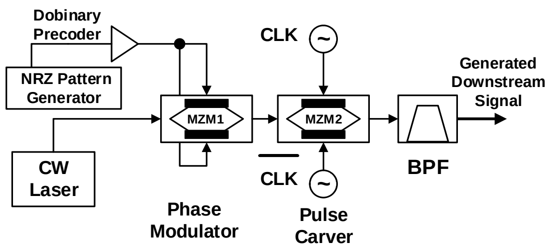

Figure 2. The optical RZ-DPSK transmitter

The reasons of using DPSK format, a balance detection method for DPSK system successfully used for large tolerance to signal power variations in the receiver decision. No carrier component needed in DPSK receiver, this makes DPSK receiver a great cost effective [13, 14]. In balance detection, the robustness to narrow-band optical filtering in DPSK system is greater than the OOK system. The DPSK system are more elastic to non-linear effects than OOK system [15]. The optical power is more evenly distributed as power is present in every bit slot in DPSK and the optical peak power is 3 dB lower than OOK in DPSK for the same average optical power. For RZ-DPSK verses NRZ-DPSK in comparison, RZ-DPSK was found to have a distinct advantage in the deep saturation regime, showing almost no distortion in the received eye diagram [16, 17].

Now the optical signal will be ready to be multiplexed and travel over SMF. Details of the bandwidth and specifications of the used WDM MUX and DeMUX is presented in Table II[18]. This work utilizes a standard optical fiber cable from real manufacture. There are many reasons to use this SMF. Availability, since it has a wide use in researches and markets as in [19, 20]. Upgrading capability, since there is no need to replace the underground cables to upgrade the network. Only OLT and ONU will be upgraded as in [21].

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TABLE II. SPECIFICATION OF MUX / DEMUX

Parameter[a]	Value	Unit
Insertion loss	2.5	dBm
Channel center accuracy	± 1.25	GHz
Frequency band	1460 - 1610	nm
Minimum Bandwidth[b]	≥ 14	GHz

a. At 50 GHz channel spacing and 16 channels.

b. Proposed system operated at 20 GHz

After traveling over SMF the transmitted optical then demultiplexed. ONU receive the downstream signal after demultiplexing to a power splitter. The first half of a typical balanced DPSK receiver is shown in Fig. 3. The optical signal is passed through a Mach-Zehnder delay-interferometer (DI), whose differential delay is equal to the bit period.

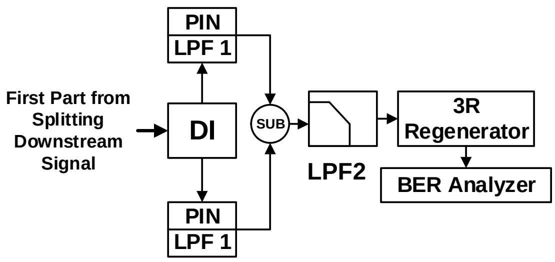


Figure 3. DPSK Receiver in each ONU.

The DI lets two adjacent bits interfere with each other in its output ports. This interference leads to the presence (or absence) of power at a DI output port if two adjacent bits interfere constructively (or destructively) with each other. Thus, the preceding bit in a DPSK encoded bit stream acts as the phase reference for demodulating the current bit. Now the signal in optical form. Basic PIN photodiode with first low pass filter (LPF) are used to convert the optical signal to electrical. The electrical subtractor is then used to extract the NRZ electrical signal again [12]. Two reasons make ONUs cost effective one, there is no need for carrier source. Second, ONU runs without laser source.

A second LPF is used to refine the electrical signal and make it ready to extract the data. Finally optical 3R regeneration (re-amplification, reshaping, and retiming) is used to limit the accumulation of signal impairments and extend the reach of the signal without repeated high-speed optical-electrical-optical (O/E/O) conversions [22]. After that a BER analyzers is used to measure the downstream system performance.

C. Upstream Transmission Process

Starting from the PS that splits the received signal from corresponding OLT into two halves. The first half is processed and received via ONU. The second half will be used as a light source for the upstream process. The other half of the DPSK signal is passed through Mach-Zehnder intensity modulator (IM). The other arm of MZM is driven by upstream data payload. The remodulated OOK upstream signal is multiplexed and transmitted back to the OLT through another SMF (without laser source). As identical wavelengths are used for downlink and uplink transmission, a dual fiber transmission structure between OLT and ONU is used for preventing transmission performance from being limited by reflections (Rayleigh backscattering and discrete reflections) [9].

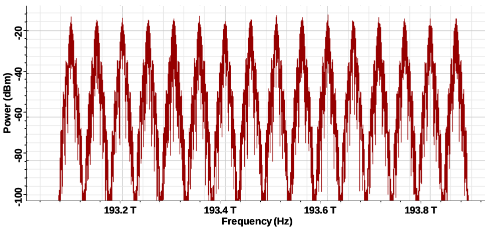
After retransmitting the required data from the ONU, upstream receiver in each OLT becomes active. In this part OLT operates as a receiver, simply by receive the optical signal with PIN photodetector and extract the data after a LPF to measure its BER [8].

III. SYSTEM EVALUATION AND OPTIMIZATION

In this section, a 16 optical bidirectional WDM-PON channelswith central source system is evaluated and optimized. The setup used for the system evaluation is shown in Fig. 1at random OLT receivers. Since the quality of received signal reflects the overall system performance. Starting with theevaluating process in order to ensure successful transmission.

D. System Evaluation

Figure 4 (a) show a multiplexed 16 optical channelswith 5 Gbit/s each DPSK coded generated from OLT downstream transmitter [18]. Channel power levels are adjusted to not exceed -20 dBm [6]. After transmitting over SMF with 60 km,the spectrum of the 16 optical channel is presented in Fig. 4 (b). A noisy spectrum was observed in frequencies intervals under 193.1 THz (channel 1) and above 193.85 THz mainly due to four wave mixing (FWM) phenomenon associated with high channel power of WDM transmission [23]. FWM is the main nonlinear phenomenon that limit the number of optical channels to 16[24].



(a) Before traveling over 60 km SMF.

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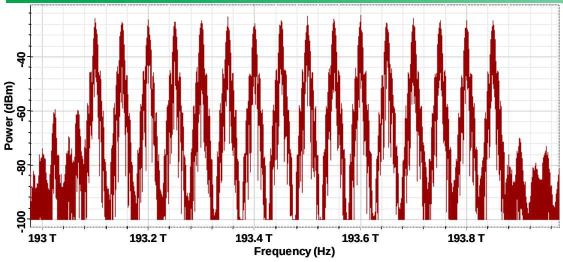
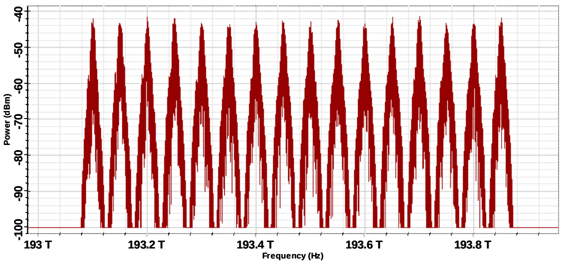


(b) After traveling over 60 km SMF.

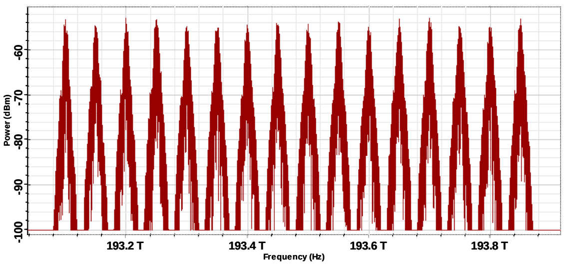
Figure 4. Downstream optical channels sprctrums

Figure5 (a) shows the multiplexed 16channel 5 Gbit/s each OOK coded after processing in the ONU and applied to a multiplexer. A reduction in the power level reach -40 dBm is observed. This is mainly due to the nature of the proposed central power scheme used in this work.

Using NRZ-OOK is compatible with the main goal of introducing low cost central power source scheme in WDM-PON networks [25, 26]. Requiring low electrical bandwidth for transmitter and receiver, insensitivity to laser phase noise and simplicity of construction are reasons for using NRZ-OOK in power saving technique.



(a) Before traveling over 60 km SMF.



(b) After traveling over 60 km SMF.

Figure 5. Upstream optical channels sprctrums

After transmitter another 60 km in upstream path, a spectrum of the 16 channel is presented in Fig. 5 (b). Compared to the same stage but for the downstream path Fig. 4 (b) one can observes two major differences. First power levels are reduced further to level of -45 dBm mainly due to the 60 km path. Second and most important is the absence of the FWM noisy spectrum observed in Fig. 4 (b). It is thought that this behavior is due to the absence of high channel power levels that can generate non-linearity process as FWM that generated in the downstream process.

E. System Optimization

The study is optimized to make this configuration flexible and to choose the optimum optical launched power. This is done for the bit rates 5 to 1 Gbit/s, respectively. The other parameters are kept the same as presented in Table I. The proposed scheme is simulated for different launched power levels targeting a maximum BER of 10^{-13}. Figure 6 shows the relation between launched optical power and BER.

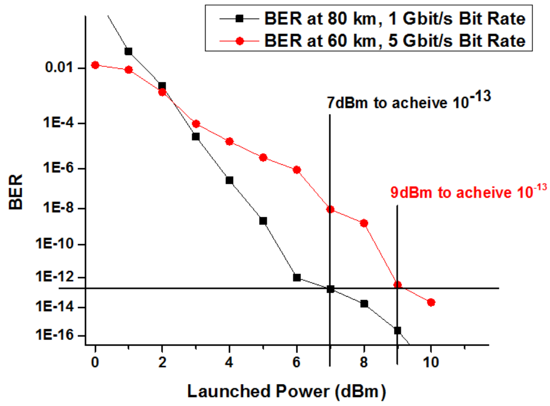


Figure 6. Optical Launched power (dBm) verses BER

It is observed that, for a fixed transmission length, as the launched optical power increases the BER enhances. Simulation results show that to achieve 1 Gbit/s add 80 km transmission distance, the minimum launched optical power should be 7 dBm. Also, to achieve 5 Gbit/s over 60 km transmission distance, a minimum 9 dBm launched optical power is required.

F. System Results

Before displaying results of BER evaluation, one needs to review the meaning of eye-diagram. The eye diagram is a useful tool for the qualitative analysis of signal used in digital transmission. It provides at-a-glance an evaluation of system performance and can offer insight into the nature of channel imperfections. Careful analysis of this visual display can give a fine representation of signal-to-noise ratio, clock timing and jitter [27]. Basic information contained in the eye diagram are the size of the eye opening, the magnitude of the amplitude and timing errors (left and right side is associated with timing errors) [28].

Since this scheme will apply for WDM-PON systems, an average BER of 10^{-13} is targeted in this

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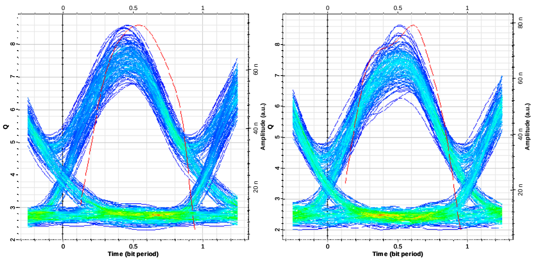
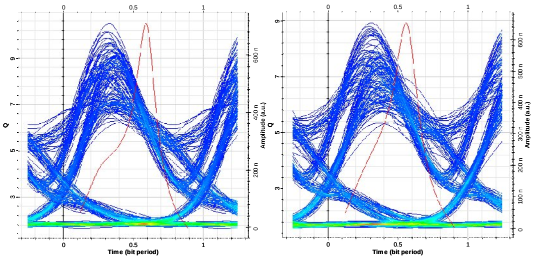
work. Many latest research targeting BER performance evaluation use eye-diagram for WDM-PON systems as in [29, 24].

Figures 7 and 8 present the eye diagrams for several random OLT receivers at the two mentioned operation scenarios. The size of the eye opening and the magnitude of the amplitude and timing errors is an evident for acceptable system performance. The maximum achieved BER of 10^{-13}.



(a) Channel 2 eye diagram ***(b) Channel 15 eye diagram***

Figure 7. Eye diagrams for random channels 2 and15 at 1 Gbit/s over 80 km. BER



(a) Channel 1 eye diagram **(b) Channel 7 eye diagram**

Figure 8. Eye diagrams for random channels 1 and7 at 5 Gbit/s over 60 km. BER

The most important information is the size of eye opening, since it obtains a bandwidth limitation and no additive noise. Hence, for reliable transmission, it is essential that the eye is kept open[1]. Excellent eye diagram (open and no timing error) leads to a low BER. Hence, to improve any system performance a very low BER should be achieved. A BER of 10^{-9} is often considered the minimum acceptable BER for telecommunication applications.

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