Modelling and performance analysis of DWDM passive optical network

S M Sadinov¹, K K Angelov², P Kogias³

¹,² Department of Communications Equipment and Technologies, Technical University of Gabrovo, 4 H. Dimitar str., 5300 Gabrovo, Bulgaria
³ Department of Electrical Engineering, International Hellenic University, Ag. Loukas, 65404 Kavala, Greece

E-mail: murry@tugab.bg, kkangelov@tugab.bg, kogias@teikav.edu.gr

Abstract. Passive optical networks are emerging as the main technology for building access networks. The current metropolitan optical communication networks operate at 1Gbps, which appears to be insufficient for the future development and exponential growth of traffic from IP services. The existing various traffic-intensive services and the growing interest in 4K video content and streaming services require the introduction of new solutions within passive optical networks (PON). A promising option is the combination of 10 Gbps and above high-speed data transmission with spectral multiplexing. DWDM will provide the required high spectral efficiency, but in contrast will require the use of a proper modulation scheme to achieve a longer distance. In this paper a model for performance analysis and solving optimization problems for DWDM-PON networks is developed. Different signal modulations are considered and a comparative analysis is performed. The behaviour of the system at different input parameters is modelled. Performance analysis is performed by evaluating the spectral characteristics and values of BER and Q-factor.

1. Introduction

Passive optical networks (PON) offer a number of specific advantages compared to active optical networks [1]. They are characterized by higher reliability and significantly easier maintenance. Of interest is the entry of 10-Gbps PON networks. In order to ensure the development of PON networks in relation to the increased volume of traffic, one possible solution is to expand the opportunities by introducing DWDM technology.

This paper examines the development and research of a simulation model of a 10 Gbps DWDM-PON network. Of interest for research are the different effects of the introduction of DWDM [2]. The main goal is to increase the bandwidth capacity of classic PON networks by applying a combination of TDM and WDM multiplexing. Figure 1 shown the main principle of the WDM-PON. The downstream channel transmits signals with varied wavelengths intended for individual clusters of subscribers. The signals are multiplexed and demultiplexed by an AWG filter.

The use of channel multiplexing will lead to effects such as four wave mixing (FWM) at narrow interwave distances, chromatic dispersion, channel crosstalk and various non-linear effects [3]. These problems lead to signal degradation as it propagates into the optical fiber.

The application of simple optical modulation techniques in most cases provide sufficient measures for the problems [4]. However, to achieve high-speed transmission in the multichannel optical transmission network, it is necessary to use more efficient modulation formats. Duobinary modulation
is a suitable option, as its wider optical signal spectrum allows to minimize the effect of chromatic dispersion and FWM [4].

![Figure 1. The principle of WDM-PON technique.](image)

This paper will present an assessment and comparison of performance using the ordinary intensity modulation format. The performance of the modelled DWDM-PON optical network will be evaluated by the result values of Q-factor, BER, spectral characteristics and eye patterns of the optical signals.

2. Overview of the analysed modulation formats

The most common methods for optical signal modulation is external optical intensity modulation [5]. NRZ modulation is a popular solution in systems with intensity modulation [4]. It is characterized by simple implementation and easy signal detection. Figure 2 shows a Mach-Zender (MZM) modulator, which is used to obtain NRZ optical modulated signals.

![Figure 2. Mach-Zender modulator (a) and its structure (b) for external optical modulation.](image)

Duobinary modulation is an amplitude modulation, with significant resistance to interference in optical fibres and nonlinear effects (FWM, cross-phase and self-phase modulations) and is characterized by high spectral efficiency. The transmission of B bits per second requires the B/2 Hz bandwidth [4], therefore the bandwidth is reduced by half compared to NRZ modulation. The bitstream in duobinary modulation is manipulated in order to reduce the bandwidth and minimize the possibility of intersymbol interference (ISI) [3, 4].

One of the main difference in duobinary modulation compared to NRZ modulation is its ability to generate optical signals with narrower bandwidth. This allows minimizing the conditions for the occurrence of FWM in DWDM systems. However, the sensitivity of duobinary modulation to polarization mode dispersion (PMD) should be noted as a disadvantage.
3. Development of a model of DWDM-PON network

Figure 3 shows the proposed model of a DWDM-PON network for 10-Gbps transmission, which is simulated by the OptiWave software platform.

An 8-channel DWDM system with wavelength distribution in accordance with Recommendation ITU-T G.694.1 [6] was modelled. The channel distance between the individual wavelengths is 100 GHz. The model includes optical transmitters, AWG multiplexer, optical transmission line, AWG demultiplexer and optical receivers.

![Figure 3](image)

**Figure 3.** Modelling of 10-Gbps PON network with dense wavelength division multiplexing.

Figure 4. Optical transmitter model with (a) external NRZ modulation and (b) external duobinary modulation.

![Figure 4](image)
Either NRZ modulated optical transmitters or DM modulated optical transmitters are used as transmitters for the 8 optical channels. The model of the optical transmitter with NRZ modulation is shown in figure 4a, and with duobinary modulation – in figure 4b, respectively.

The optical transmission line includes a standard single mode optical fiber (SMF) at 15 km length with attenuation of 0.24 dB/km and a chromatic dispersion of 16.75 ps/(nm.km). Optical attenuators with 0.5 dB attenuation have also been added to model the presence of SC/APC connectors.

After the demultiplexer, 8 optical receivers are presented, each of which is 1 km away from the others. The proposed model can be applied in system with different optical line lengths to determine their performance and behaviour.

On figure 5 is showed the developed model of one of the receivers. The signal is initially fed to a band-pass Bessel optical filter, which removes the products from the nonlinear effects. The second block is PIN photodiode, which detects and transform the optical into electrical signal (with responsiveness of 1A/W). The second filter (low-pass Bessel electronic filter) applies a fine-tuning of the electrical signal.

The parameters and characteristics of the optical system are measured and displayed using different visualizers: optical spectrum analyser, optical power meter and BER analyser (figure 5).

![Figure 5. Optical receiver model.](image)

4. Results
In figure 6 are shown the measured spectral characteristics for both types of modulated optical signals at the output of the AVG multiplexer.

![Figure 6. Spectrum of modulated optical signals at the output of the AWG multiplexer for (a) NRZ modulation and (b) duobinary modulation.](image)
Figure 7. Spectrum of modulated optical signals at the input of the AWG demultiplexer for (a) NRZ modulation and (b) duobinary modulation.

In figures 8 and 9 are shown the eye patterns of the received and demodulated signals obtained at the outputs of the nearest and farthest optical receivers, respectively.

Figure 8. Eye pattern of the received and demodulated signal at the output of an optical receiver RX1 for (a) NRZ modulation and (b) duobinary modulation.

Figure 9. Eye pattern of the received and demodulated signal at the output of an optical receiver RX7 for (a) NRZ modulation and (b) duobinary modulation.

Figures 7 and 9 clearly show the effect and advantage of duobinary modulation format. The BER analyzer determines the dimension of the BER/Q-factor of the signal for the two different modulation
schemes and for different lengths of the fiber-optic (i.e. for different optical receivers 1 to 7). The results are shown in figure 10, where the value of the Q-factor of 16.94 dB corresponds to the maximum acceptable value of BER = 1.10^-9.

![Figure 10. Dependence of the Q-factor on the optical fiber length for the two different types of modulation](image)

5. Conclusion
The results of the simulation clearly show the advantages of the optical duobinary modulation scheme. The application of duobinary modulation format in DWDM-PON systems make available of a bigger number of communication channels per unit bandwidth, i.e. using more densely spaced wavelengths. The narrower frequency spectrum leads to greater signal stability in the event of ISI and FWM.

6. References
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