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A novel architecture of hybrid (WDM/TDM) passive optical networks with suitable modulation format

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ABSTRACT

In this paper, we have analyzed the performance and feasibility of a hybrid wavelength division multiplexing/time division multiplexing passive optical network (WDM/TDM) PON system with 128 optical networks units (ONUs). In the proposed network, the triple play services (video, voice and data) are successfully transmitted to a distance of 28 km to all ONUs. In addition, we investigate and compare the proposed hybrid PON for suitability of various modulation formats for different distance. It has been observed that the most suitable data format for hybrid PON network is NRZ Rectangular.

1. Introduction

Recent advancements in services have drawn attention onto access networks for high bandwidth demand as they represent a bottleneck in the last mile towards the customer [1]. The prominence is put on high bit-rate transmission, network reliability and survivability to reduce operational expenditures and network coverage, scalability to reduce capital expenditures [2]. Researchers are aiming at optical access network concepts known as hybrid wavelength-division-multiplexed time-division multiple access passive optical networks [3]. The networks are designed to be beneficial for operators due to low capital and operating expenditures [1]. Various techniques and components of the network are designed to achieve high data rate transmission to large bandwidth such as tuneable optical add/drop multiplexer (OADM) [2], colorless ONU [4], self-homodyne and differential coding [5], a reflective semiconductor optical amplifier (SOA) [6] and Bragg reflectors [7]. The passive optical networks are constituted of a centralized optical line terminal (OLT), located in the central office and a number of ONUs located at the users' premises to some distance away from the OLT.

In the upstream direction, the traffic is transmitted from the ONU to the OLT whereas in the downstream direction, the traffic is transmitted from the OLT to the ONU through one fiber [8]. The requirement of local light sources for the ONUs can be avoided by using reflective designs and this type of ONU design can contribute to a low-cost deployment in carrier-distributed PONs [9]. To seed downstream traffic at ONUs with optical signals for their upstream data transmission, a wavelength-specified laser is advantageous over generating multiple wavelengths because no statistical gain can be exploited among ONUs that can support different wavelengths, facilitates the statistical multiplexing of traffic from all ONUs, thus potentially yielding better system performance, enable the color-free property of ONUs, which further facilitates the simplified inventory management, reduced sparing cost, and automated wavelength provisioning [10].

Urban et al. [2] transmitted two 1.25-Gb/s wavelength channels over 26-km standard single-mode fiber carrying data to and from the user. The experiments on the test bed of a hybrid wavelength-division-multiplexing/time division-multiplexing access network based on cost-efficient elements like an integrated optical add–drop multiplexer and a reflective semiconductor optical amplifier were carried out.

Oh et al. [7] reported a tunable external cavity laser (T-ECL) using a super luminescent diode (SLD) and a polymer Bragg reflector with 0.8-nm mode spacing 25 channels operating in the direct modulation of 2.5 Gb/s for a low-cost source of a wavelength division multiplexed passive optical network (WDM-PON) system. The T-ECL was successfully operated in the direct modulation for 2.5-Gb/s transmission through 20-km standard single-mode fiber.

Kaler et al. [11] employed Giga Ethernet Passive Optical Network (GE-PON) architecture with 1:8 splitter. The architecture was based on a PON element to establish communication between a central office to different users. GE-PON architecture for 10 Gbit/s

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has been investigated for different lengths from a central office to the PON in the terms of the BER up to 15 km.

Wason et al. [12] proposed an efficient wavelength assignment algorithm for dynamic provisioning of light-path. The proposed algorithm was based on most-used wavelength assignment algorithm. A mathematical model for WDM optical networks for minimization of blocking probability was also proposed. The results of proposed algorithm and suggested model were compared with the conventional wavelength assignment algorithms such as first-fit, best-fit, random and most-used wavelength assignment algorithms.

In literature, various works on hybrid passive optical networks has been reported. Considering [2], only two 1.25-Gb/s wavelength channels are transmitted through single-mode fiber up to a distance of 26-km. In [7], T-ECL based WDM PON is reported in which 25 wavelength channels are transmitted up to a distance of 20 km. Similarly, in [11], GE-PON is investigated up to 15 km. Till now, we observe that the number of ONU's proposed in hybrid passive optical network are limited to lesser number of ONU's, up to short distance and optimization of modulation format is not yet done. In this paper, we extended the previous work by increasing the number of ONU's and investigated the performance of hybrid passive optical networks. We simulated hybrid PON architecture for a bit rate of 1.25 Gbit/s for 128 users. Data and voice signals are combined and transmitted at the wavelength of 1480–1500 nm and RF SCM (radio frequency sub-carrier multiplexed) video signals are modulated using phase shift keying (PSK) at the wavelength of 1550–1560 nm. We have also compared the different modulation formats and find the best among these for hybrid passive optical network.

This paper is organized into four sections. In Section 1, introduction to hybrid passive optical networks is described. In Section 2, the simulation setup for hybrid PON is described. In Section 3, comparison results have been reported for the different modulation formats. Finally in Section 4, conclusion and future scope are made.

2. Simulation setup

The block diagram of simulation setup for hybrid passive optical network is shown in Fig. 1. In the proposed system setup 128 users can use triple play services (data, voice and video) up to 28 km without using any repeater. In this system, central office is equipped with OLT devices, and an ONT device is installed on the subscriber end. Fiber distribution is done using a tree-and-branch architecture. The OLT is connected to 128 subscribers by splitting the fiber to 16×8 times. The proposed architecture models of hybrid passive optical network design with 128 subscribers and 28 km distance.

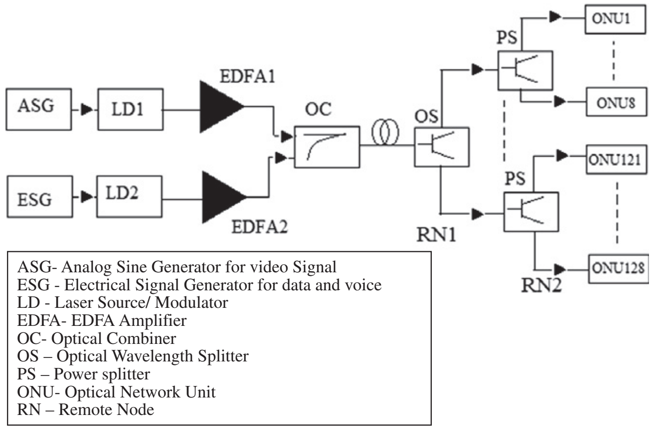

Fig. 1. Block diagram for hybrid passive optical networks.

By taking the quick look over different literature, it is evident that the term "triple play" service stands for three services: voice, internet and video. The combination of data, voice and video signals are realized at the central office. The high speed data components are realized by a downstream data link with 1.25 Gb/s bandwidth. These signals are generated using Electrical signal generator with pseudo-random data generator (PRBS). The voice components are represented as VOIP (voice over IP, packet-switched protocol). These signals (data and voice) are combined in physical layer simulation and transmitted using RZ/NRZ or Manchester modulator driver, direct modulated laser and booster amplifier. At direct modulated laser source, the wavelength is kept in the range of 1480–1500 nm for the transmission of these combined signals.

The video components are represented as RF SCM system with two channels with 55.25 MHz and 547.25 MHz frequencies. PSK modulation scheme is used to carry video signals in the channels. These signals are generated using two analog signal generators, summer, direct modulated lasers and pre-amplifier. These signals are transmitted within the 1550–1560 nm range. EDFA pre-amplifier is used to boost up these signals before transmitting. The combined data/voice and video signals are further combined using optical combiner and launched to the channel. The signal from the central office transmits through two remote nodes to ONU. A fiber trunk of varying length (10–35 km) is installed at first remote node with 1:16 optical splitter. All of these 16 outputs travel through another 1 km fiber (with different time delay parameters) to reach second remote node where 1:8 power splitter is used to feed the signal to 8 individual channels. The signal has a 3-dB pulse width of 5 ps. The second remote node consists of pulse train generator, power splitter and delay blocks. The signal of each channel is received at each ONU by 10 ps delay i.e. the signal will reach at first ONU with zero time delay and at second ONU with 10 ps delay and so on. At the ONU, these signals further demultiplexed into video signals and Data/voice signals using optical Fabry–Perot filters, with the center wavelength set for the desired service. Then each of the filtered signals goes into avalanche photo detector (APD) and followed by different testers to analyze the results. The BER and Q factor are most commonly used performance parameters. The Q factor can be defined as:

$$Q = \frac{m_1 - m_0}{\sigma_1 + \sigma_0} \tag{1}$$

where m_1, m_0 are the mean of the received signal at the sampling instant when a logical 1 and 0 is transmitted and σ_1, σ_0 are the standard deviations respectively. BER can be estimated by the following inverting formula:

$$\mathrm{BER} = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right) \tag{2}$$

The jitter value is evaluated as the standard deviation of the position of the maximum of the received signal with respect the specified sampling instant or bit frame. This maximum received signal depends upon the decision threshold which is related to the highest Q value or lowest BER value. Jitter can be estimated as the standard deviation of the random variable at bit duration T:

$$\Delta J_i = J_i - J_i^{\max} \tag{3}$$

where J_i is the time frame to synchronized the bits and $J_i^{\max}$ is the maximum signal for each bit and can be represented as

$$J_0 + iT < J_i^{\max} < J_0 + (i+1)T \tag{4}$$

To visualize optical spectrum, waveforms, eye diagrams, etc. various measurement instruments like optical spectrum analyzer, power meter, Q estimator and BER estimator have been placed. Various eye diagrams at different frequencies are taken. The Q factor, jitter and BER values are also calculated to verify the results.