MODULATION FORMATS TESTED IN WDM-PON

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Abstract: This paper focuses on binary modulation formats and their influence of performance in wavelength division multiplexing passive optical networks (WDM-PON). WMD-PON uses separate wavelengths for each end unit and arrayed waveguide gratings for signal division in comparison with current PONs based on time division multiplexing and signal division in passive optical splitters. There are several binary modulation formats which can improve a quality of signal and suppress nonlinearities and dispersion effects.

Keywords: binary modulations, wavelength division multiplexing, arrayed waveguide grating

1. INTRODUCTION

Fiber-to-the-home (FTTH) optical networks are typically realized as passive optical network (PON) systems. PON provides a point-to-multipoint access between one optical line terminal (OLT) and several optical network units (ONUs) through the use of time-division multiplexing (TDM) in the downstream traffic from the OLT to the ONUs, and time-division multiple access (TDMA) for the upstream traffic from the ONUs to the OLT. Data bit rates depends on standards and varies between 1 Gb/s and 10 Gb/s.

Earlier optical communication systems mainly used non-return-to-zero (NRZ) modulation format. The demand for high transmission capacity leads to the creation of new modulation formats. Chirped RZ (CRZ) is a special type of return-to-zero (RZ) modulation implemented by the pre-chirp on RZ pulses. This modulation format is usually used in long-haul transmission links. Carrier-suppressed RZ (CSRZ) modulation is a recent modulation format for high-capacity transmission links. Earlier studies were concerned with the influence of modulation formats on fiber optics nonlinearities and dispersion effects. In this paper, we have estimated the performance of NRZ, 33%RZ, 50%RZ, CSRZ and CRZ modulation formats in 2.5 Gb/s passive optical network based on wavelength division multiplexing.

2. WDM-PON DESCRIPTION

Wavelength-division-multiplexing passive optical networks (WDM-PON) have become a promising solution for the next-generation of fiber-to-the-home (FTTH) architecture because of its almost-unlimited bandwidth, security, and protocol transparency. But this requires expensive wavelength optical sources with narrow spectral spacing so that it hasn't been mostly deployed. WDM-PON is defined as a PON system in which each optical network unit (ONU) uses a different, unique wavelength in each direction to communicate with the optical line terminal (OLT). Fig. 1 shows a basic WDM-PON configuration. OLT consists of several transceivers corresponding to the number of ONUs. Each transceiver emits the downstream signal with a wavelength λ_{DOWN-k} (k = 1 to n) and receives the upstream signal with a wavelength λ_{UP-k}. An arrayed waveguide grating (AWG) is used to the wavelength multiplexing of downstream and upstream signals. The most unique feature of WDM-PON is that point-to-point communication between transceivers and ONUs is implemented logically. Therefore, this system is some-times called the "virtual point-to-point" system [1].

The mux/demux devices, other important components for the WDM-PON, are shown in Fig. 1. They are typically placed outdoors; so that the temperature and humidity tolerance must be higher than similar devices in indoor offices. Moreover, the mux/demux devices must be completely passive because it is difficult to supply power to the outdoor device without increasing costs. From these reasons, arrayed waveguide gratings (AWGs) [2] and thin-film-based WDM filters are suitable components for WDM-PON applications. AWGs have a typical insertion loss of 3-5 dB independently of the number of output ports.

The power budget, i.e., the acceptable loss between OLT and ONUs in WDM-PON systems is typically much higher than that of simple PON systems because the architecture is typically a combination of passive optical splitters with higher insertion loss, which increases with increasing number of output ports, e.g. a 1:8 splitter have insertion loss of 10.4 dB. The transmission distance of current PON is limited up to 20 km, on the other hand WDM-PON can operate over a distance of 50-80 km.

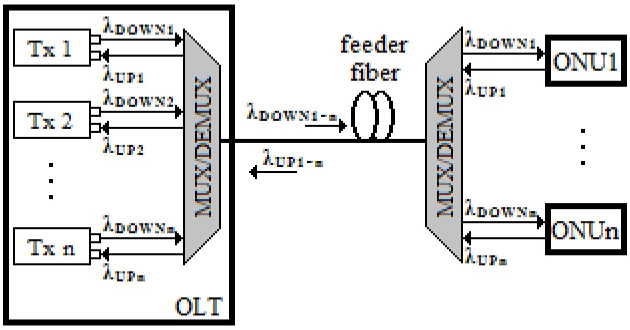

Figure 1: Scheme of WDM-PON connection

3. BINARY MODULATION FORMATS

Return-to-zero (RZ) means that the width of optical signal is shorter than a bit slot. In the RZ modulation format, each binary 1 occupies only a portion of the bit slot and then drops to a binary 0 to the end of the bit slot. RZ modulation is generated by sending an NRZ optical signal into a second modulator with a sinusoidal driving function. RZ modulation has three currently used forms: RZ with 50% duty cycle, RZ with 33% duty cycle, and carrier-suppressed RZ (CSRZ) with 67% duty cycle. All RZ pulses have exactly the same pulse shape, independent of the neighboring bit values. The phases of the RZ pulses are identical and chirp-free in the case of ideal modulation. The optical spectrum of the 33% RZ and 50% RZ signal are much broader than in the case of the NRZ signal due to the narrower width of the RZ pulses.

Non-return-to-zero (NRZ) is the most basic modulation format in fiber-optical communication systems because of the low electrical bandwidth and the simplest configuration of transceivers [3]. In the NRZ modulation format, each binary 1 occupies an entire bit slot and does not drop to a binary 0 during the bit slot duration. The signal intensity changes between a binary 1 and 0 when the bit sequence changes between these states. The phase of a binary 1 is π and there is no phase of a binary 0. All the pulses have the same phase for NRZ signal. The optical spectrum of the NRZ signal has sharp peaks at multiples of the bit rate [4]. The NRZ signal has the most compact spectrum in comparison with other modulation formats. However, this does not mean that the NRZ signal is more tolerant to Cross-phase modulation (XPM) and Four-wave Mixing (FWM) in Dense Wavelength-division multiplexing (DWDM) systems because of its strong carrier component in the optical spectrum. NRZ may not be the best choice for high-capacity optical systems [5].

Chirped RZ (CRZ) pulses with 50% duty cycle are generated with the same parameters as the 50% RZ except the nonzero chirp factor. The chirp factor varies between ±1 if a less expensive single-drive modulator is used. Bit-synchronous periodic chirp spectrally broadens the signal bandwidth. The central lobe is broader than the central lobes of 50% RZ and CSRZ. Although this reduces the format suitability for high spectral efficiency WDM systems, it generally increases its robustness as regards fiber nonlinearity [6]. CRZ can increase the capacity, system reach and performance in long-haul point-to-point fiber links [7].

Carrier-suppressed RZ is generated in the second sinusoidal modulator fed by an NRZ optical signal. The sinusoidal drive voltage has twice the 50% RZ frequency and swings at twice the amplitude. This is considerable different from the standard RZ modulations. The phase of the pulses varies by π every consecutive bit period. This leads to destructive interference with the carrier frequency. The optical spectrum has no peak at central frequency. It helps to reduce the interactions between neighboring pulses and this improves signal quality [3].

4. SYSTEM CONFIGURATION

All simulations have been calculated by using the OptiSystem v.6 software. The passive optical network based on the wavelength division multiplexing with a 1:8 AWG has been chosen for comparing binary modulation formats. Optical pulses from the optical line terminals (OLTs) are generated using the Mach-Zehnder Modulator at 2.5 Gb/s bit rate. Transmission wavelengths are different for each end unit. The central wavelength is 1550 nm and the spacing between wavelengths is 0.8 nm in the first simulation and 0.4 nm in the second simulation. Different approaches of WDM-PON use this wavelength because of the lowest attenuation coefficient of optical fibers. This is main difference in comparison with current PON, where this wavelength is dedicated for video distribution.

The optical pulses at different wavelengths from lasers go to the circulators. A circulator serves to separate wavelength for the downstream and upstream traffic. All downstream signals are combined in the first 8:1 AWG into one optical fiber. A spectral characteristic for the downstream traffic can be seen in Fig. 2.

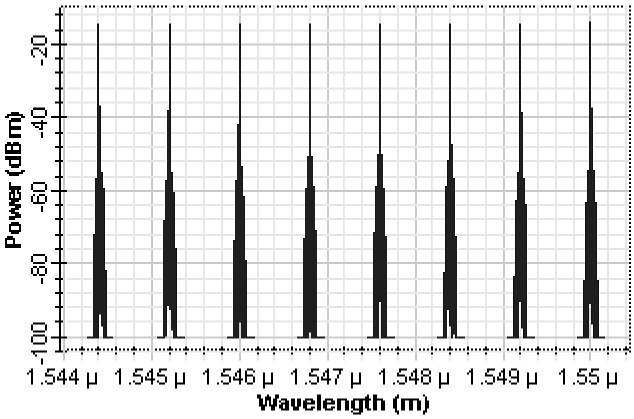

Figure 2: Spectral characteristic at the output port of the 8:1 AWG for NRZ modulation format with 0.8 nm wavelength spacing.

The pulses travel through a 55 km link comprising the single mode fiber (SMF) with an attenuation of 0.24 dB/km at a wavelength of 1550 nm. At the end of the link the second 1:8 AWG with is connected. The insertion loss of AWGs is much lower in comparison with a passive optical splitter used in PON. The main advantage of AWG is that the insertion loss is 3 dB and it does not increase with the increasing number of output ports as for passive splitters.

Optical network units are compound of a circulator, a PIN diode and an upstream transmitter. The circulator serves to separate the downstream traffic from the optical fiber and to join the upstream traffic into the optical fiber. The PIN diode is used for the detection optical pulses and conversion to analog format. The transmitter in each ONU is set at different wavelengths as for the OLT.

5. RESULTS OF SIMULATION

The investigations were carried out on an optical link 55 km long, with data rate 2.5 Gb/s and transmitter power of -3 dBm. We chose wavelength spacing of 0.8 nm in the first simulation. The central wavelength was 1550 nm because of the lowest attenuation coefficient of optical fibers. Others channels were set at lower wavelengths, as can be seen in Fig. 2. WDM-PON allows communication over a longer distance compared with current PON. We set the transmission distance of 55 km and we observed the BER and Q-factor for all modulation signals. The BER was 10^{-9}, 10^{-4}, 10^{-6}, 10^{-8} and 10^{-4} and the Q-factor was 5.91, 3.67, 4.62, 5.53 and 3.14 for NRZ, 33%RZ, 50%RZ, CSRZ and CRZ, respectively. The BER of 10^{-4} is marked as non-acceptable and additional forward error correction (FEC) must be used to improve the BER up to 10^{-12} which is marked as very good.

We tested the maximal transmission distance with a BER of 10^{-12} and the distance with a BER of 10^{-4} where FEC must be implemented. Fig. 3 shows the dependence of BER vs. transmission distance. The longest transmission distance can be achieved in using NRZ modulation. The highest BERs were for CRZ and 33%RZ modulations and there must be used FEC when the distance is 55 km. For this distance, 50%RZ, CSRZ and NRZ modulations can be used without FEC.

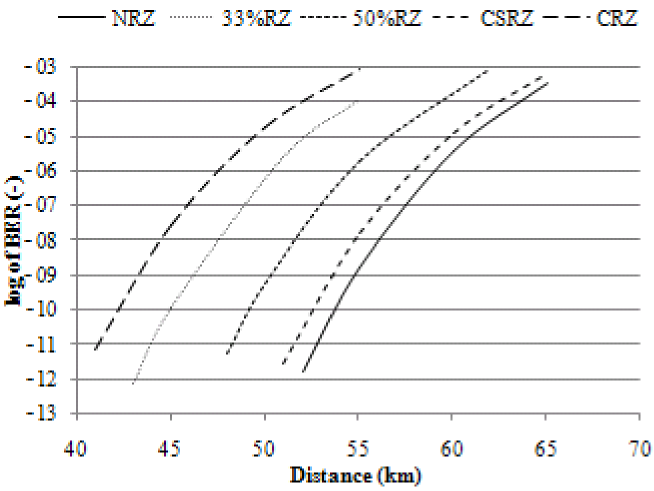

Figure 3: Dependence of BER on transmission distance.

6. CONCLUSION

The simulations has shown, that CRZ is not suitable for optical link based on wavelength division multiplexing because of the broader central lobe which affects adjacent spectral channels. CRZ has potential to be used in point-to-point optical link over long distance. CSRZ is modulation used in point-to-point WDM systems thanks to their narrow central lobe. Also, it can be supposed that CSRZ going to be the best simulation for WDM-PON. Our simulations have shown that NRZ modulation gives the lowest BER in the investigated network only with 8 end users. Communication over long distance is the main advantage of WDM-PON in comparison with PON. The transmission distance can be extended up to 60 km. Just for a comparison, current PON allows communication up to 25 km.

ACKNOWLEDGEMENT

This paper has been created within the frame of the project "Amplifiers for FTTH" at École supérieur d'Ingénieurs en génie electrique – Rouen. This paper has been created within the frame of the project BD18117001 – Research of electronic communication systems.

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