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Adding channels with PSBT format at 40 Gbit/s in an existing 10 Gbit/s optical network

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ABSTRACT

Until recently, the wavelength-division-multiplexed (WDM) transmission system has reached record capacities and distances due to innovations such as FEC (Forward Error Correction), distributed Raman amplification, new transmission fiber and advanced optical format. Optical-communication systems exclusively employed conventional On-Off Keying signals in either Non-Return-To-Zero (NRZ) or Return-To-Zero (RZ) format. Recently a number of advanced modulation formats have attracted attention. Some of these formats carry information through On-Off-Keying but also modulate the optical phase in order to enhance the robustness of signal to chromatic dispersion, optical filtering and non-linearities. Through extensive sets of simulation results, we showed that it is possible to replace a channel with higher bit-rate on existing DPSK or OOK at 10*Gbit/s* transmission link. Duobinary formats are ideal candidates to do it and are known for their low spectral range and high tolerance to residual chromatic dispersion. These particularities make them very attractive for both high bit rates and high distance-transmissions. Today, Phase Shaped Binary Transmission (PSBT) is considered as being the promising format for the deployment of 40*Gbit/s* technology on existing links at 10*Gbit/s* WDM long haul transmissions.

1. Introduction

In this paper, we will study the performances of PSBT (Phase Shaped Binary Transmission) with OOK (On-Off Keying) or DPSK (Differential Phase-Shift Keying) formats for a mixed 10/40*Gbit/s*, 100*GHz* spacing wavelength-division-multiplexing (WDM) grid through Nx60 km spans of standard single mode fiber (SSMF).

We have focused our work on an existing configuration for metropolitan network in order to follow the robustness to accumulation of ASE noise, chromatic dispersion, PMD and intra-channel non-linear effects. Substantial performance improvements are obtained with these formats in long haul transmission. We have shown that transmission distances can be enhanced. Our research is focused on assessing the implementation of cost-effective 40*Gbit/s* modulation technology in future generation high bit-rate robust optical transmission system. In upgraded system from 10*Gbit/s* to 40*Gbit/s* data rates, it would be ideal if 40*Gbit/s* channels could be added step-by-step in response to increased traffic demands. Few experiments have addressed the performance of such hybrid systems [1]. Using 40*Gbit/s* PSBT and 10*Gbit/s* NRZ (RZ) OOK, 100*GHz* spaced channel have been transmitted over $12\times 60km$ on the same link. In this study, we have tried to implement Optical PSBT channels in the middle of RZ-OOK (or DPSK) channels. The hybrid transmissions system is constituted by five distributed feedback (DFB) lasers operated on a 100 GHz grid and ranged from 1549.31*nm* to 1552.52*nm*. The mixed solution on the same link with format PSBT at 40 Gbit/s and RZ-OOK (or DPSK) at 10*Gbit/s* is an excellent way to upgrade existing RZ-OOK metropolitan network.

In this paper, we will compare the performance of RZ-OOK, NRZ (RZ)-DPSK and PSBT formats in an SSMF recirculating-loop. After a few kilometers transmission, we have found substantial performance differences, demonstrating that the newer duobinary formats like PSBT can greatly outperform the other formats.

2. Interest of the PSBT in a WDM transmission link

A 10*Gbit/s* optical link is designed with standards rules. The aim is here to keep this link and upgrading it with an adapted modulation format like PSBT in order to increase the bit rate. The goal is to keep standard rules of a 10*Gbit/s* link like Polarization Mode Dispersion (PMD) tolerance of 10*ps* (mean), Chromatic Dispersion (CD) tolerance of $\pm 700ps/nm$, and transmission at 50 GHz channel spacing. ALCATEL were the first to use PSBT in 1996 [2] and showed the interest of this new modulation format. It was showed that this format was able to transmit far beyond the chromatic dispersion. This is due to the π phase shift occurring in each successive opposite bit (e.g.: « 0 » and « 1 »). The tolerance to dispersion was shown at 10*Gbit/s* up to 210*km* for the first time and allowed to extend the dispersion limit [3]

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[4]. This format had been experimented on enhanced techniques even though it was already a good candidate to increase bite rate on links. The spectral efficiency versus an NRZ format is reduced by a factor of two. The electrical PSBT needs a precoder with a penalty of sensitivity amounting to 4 dB. Remodulating with NRZ signal in order to improve the extinction ratio showed the techniques enhanced the electrical PSBT. An up-to 10 dB electrical E-PSBT was experimented on this format for WDM transmission [5]. The optical PSBT using an MZI coding modulator after a DPSK was demonstrated at 42,7 Gbit/s and was compared with NRZ format showing reduced OSNR penalty by 0.7*dB* and 1.3*dB* for 4.10^{-3} (FEC limit) and 10^{-5} BER, respectively [6]. The optical PSBT was enhanced too with a remodulation MZM (Mach-Zehnder Modulator) technique up to 3*dB* extension ratio (noted *3 dB* E-OPSBT). This remodulation allowed a 0.7*dB* noise reduction at a 10^{-9} BER and kept the tolerance of GVD at 100*ps*/*nm* [7].

The main subtlety came from the use of a single *50 GHz* ITU (International Telecommunication Union) periodic optical filter applied onto a WDM multiplex of 43*Gbit*/*s* DPSK signals. It allowed to simultaneously generate optical PSBT signals, which can then be transmitted on a pre-existing 10 Gbit/s infrastructure. This could then increase the system capacity and information spectral density by a factor of four. The first demonstration was to reach a 40*Gbit*/*s* PSBT channel in order to up-grade an installed 1700*km* system [8].

In this paper, the up-graded aspects have been analyzed with the insertion of a 40*Gbit*/*s* O-PSBT on links with RZ and NRZ DPSK and OOK. This format is not only for these kinds of uses but is also used to reach records like a 3.2*Tbit*/*s* [9] and a 6.4*Tbit*/*s* over 2100*km* [10]. Here, the overview of PSBT insertion with other formats shows the capability for future up-graded installed links. The first approach was experimented with OOK last year with good results between OOK and PSBT mixing on the same link [11]. Using DPSK format, we obtained relevant results. Improvement of cost reduction could be the next generation FEC or modulation formats on already deployed links. Using PSBT on conventional SMF fiber and a dispersion maps allows enhancement of the bite rate without increasing cost.

3. System simulations

A set of system simulations was carried out in order to study the overall system performance, including a variety of impairments present in realistic metropolitans network. The simulations scenario studies a five-wavelength-channel-system with 100 GHz channel spacing in the C-band.

The transmitter line is composed of $N \times 60km$ spans of SSMF fiber, each followed by an in-line erbium-doped fiber amplifier (EDFA having a noise figure of 6*dB*) containing a dispersion-compensating fiber (DCF) module (10*km* each) as shown in Fig. 1. The gain of amplifiers is equal to the fiber losses in each span and imposes a power level at a DCF input in order to reduce the non-linear effect, chromatic dispersion and crosstalk. The SSMF fiber is assumed to have $D = 16.75ps/nm/km$, and an optical loss coefficient $\alpha = 0.2dB/km$. High local dispersion in the SSMF ensuring that nonlinear effects have an insignificant impact on the system performance. The DCF has $D = -80ps/nm/km$, $\alpha = 0.6dB/km$. For each channel, the signal was generated by modulating a single-frequency laser by a 2^7-1 Pseudo-Random Binary Sequence (PRBS). The difference with a $2^{13}-1$ PRBS length is stable and less than 0.45 on the Q factor. So, the 2^7-1 PRBS length is enough to have a good evaluation of the BER and optimize the computation time. The continuous wave of DFB lasers in our WDM system is adjustable, and the power is maintained at 0 dBm (and 6 dBm) along all the simulations.

At the receiver, signals are demultiplexed using a demultiplexer with a Gaussian characteristic.

For each of the amplitude-modulation-formats, a direct detection receiver is used. In the case of NRZ (RZ) DPSK modulation, the information is encoded in the phase of the optical field and a balanced direct-detection receiver, with a Mach-Zehnder Interferometer (MZI), is used. This receiver is preferred since, in contrast to single-ended DPSK receiver, it out performs the On-Off receiver by approximately 3*dB*, if the optical noise is an additive white Gaussian noise (AWGN), such as the ASE. The demodulated signal is then detected using a photodiode circuit connected to a low pass Bessel filter and demultiplexer. In the case of PSBT format after photodiode PIN, a 1*nm* optical band pass filter used for noise limitation is introduced according to the range wavelength of 1*nm* wide.

The transmission quality was evaluated by comparing the received data sequence with the initial one. The bit-error-rate (BER) test set receiver was programmed for the expected output sequence from the demultiplexer.

In order to better understanding simulations, the optical budget is mentioned in the following table. For each format, the power laser is maintained at 0 dBm or 6 dBm. In Fig. 1, several power meters are placed along the link with annotation P_x and are referenced in Table 1.

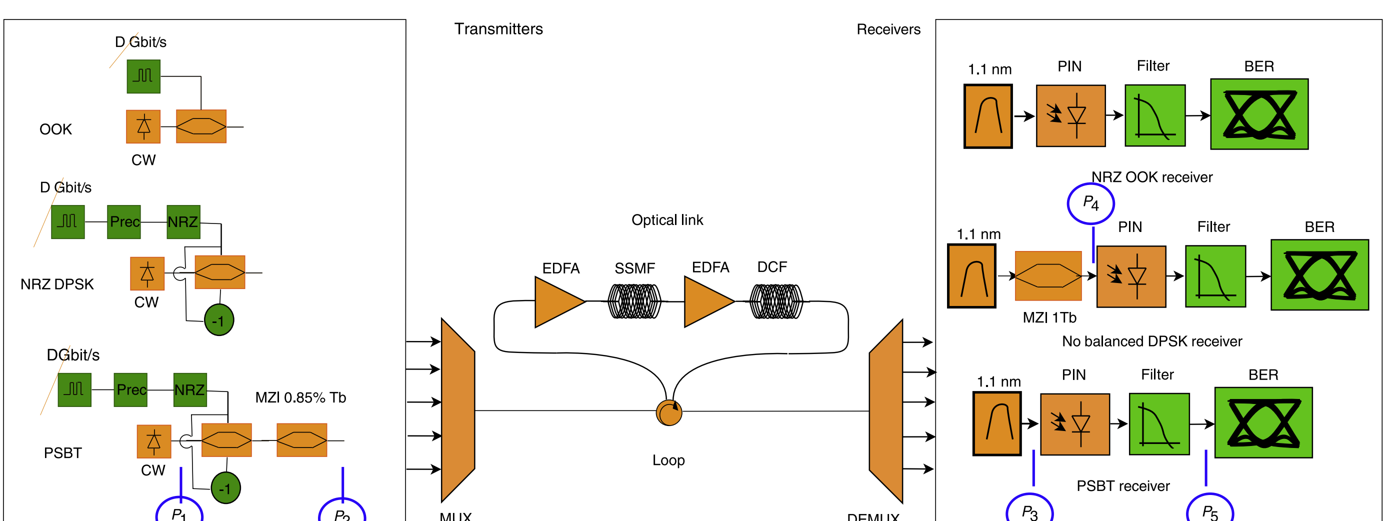

Fig. 1. Configuration setup of a metropolitan simulation link for five channels with DPSK or OOK and PSBT modulation formats. The PSBT is only introduced in the middle channel.