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Performance analysis of OTDM system in the presence of FEC using symmetric Mach–Zehnder switch

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Abstract

Optical time division multiplexing is an emerging and promising alternative for future high-speed photonic networks because of its ability to accommodate higher bit rate and flexible bandwidth. SMZ have been found to be the most suitable switching element than all the available de-multiplexing switches because of compact size, thermal stability, and low-power operation. In this paper, we simulate four channel OTDM systems (all-channel multiplexer and de-multiplexer) with a Mach–Zehnder modulator and an SMZ de-multiplexer to investigate the impact of FEC on the OTDM system. It is observed that the presence of FEC in OTDM transmission can greatly improve the system performance.

Keywords: Optical time division multiplexing (OTDM); Pcontrol; Symmetric Mach–Zehnder (SMZ); Forward error correction (FEC)

1. Introduction

Extensive research has been carried out over the years in developing practical OTDM systems, considering its vast potential in future high-speed photonic networks [1–5]. They have used periodically poled lithium niobate hybrid integrated with planar lightwave circuit for multiplexing of different channels and studied all-channel multiplexer (MUX) and de-multiplexer (DEMUX) systems. Morari et al. presented a new technique, electro absorption modulator, as MUX and DEMUX with phase-locked loop clock recovery [6]. Forward error correction (FEC) coding techniques help optical links to achieve higher performance by detecting and correcting errors on the link. FEC allows a predetermined amount of error to occur during transmission, and detects and corrects them at the receiving end. These techniques, previously used in wireless systems and data storage applications, are now being widely used in optical telecommunications systems, especially long-haul applications. Almost without exception, all modern transoceanic systems starting with TPC-5 (1996) use FEC. Two ITU specifications – ITU-T G.709 and ITU-T G.975 – recommend FEC in transmission systems. Performance improvements due to FEC can be used to increase inter-amplifier spacing and/or to increase the system capacity, to relax the specifications on the optical components or fiber (hence lower cost), and so on. In a WDM system these capacity

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improvements can be achieved by increasing the bit rate of each WDM channel or by decreasing the channel spacing, allowing more WDM channels for a given amplifier bandwidth. The disadvantage of using FEC is that the inserted check symbols consume bandwidth within the communications channel and a system using FEC requires a slightly higher bit rate to support this additional correction data. There are a large number of error-correction codes, each with different properties that are related to how the codes are generated and consequently how they perform. Some examples of these are the linear and cyclic Hamming codes, the cyclic Bose–Chaudhuri–Hocquenghem codes, the cyclic Golay and Firecodes, and the Turbo convolutional and product codes. The codes that are most attractive at present for application in high-bit-rate communication systems are a set of cyclic, non-binary, block codes known as Reed–Solomon (RS) codes. RS codes are described as (N, K), where N is the total number of symbol bits per code word, K is the number of information symbols (data bits), and R is the number of check symbols (N–K). The overhead of the code is simply the ratio of the check symbols to code word symbols. For example, the RS codes used in ITU-T G.709 and G.975 are both (255,239), so it will consist of 239 information symbols and 16 check symbols with about 6.7% overhead. Efficiency of FEC is measured by coding gain (in units of Q-factor in dB). To achieve a BER = 1.0E-13 (corresponding $Q = 17.3$ dB) after FEC with the RS (255, 239) code, the raw BER before FEC has to be 1.42E-4 (and corresponding $Q = 11.20$ dB). Here, if we compare two identical systems, one with and the other without FEC, then the gross FEC coding gain is about 6 dB, whereas the net coding gain has to take into account the bit rate overhead and is system dependent (system length, bit rate, etc. will define system impairments). So, the transatlantic WDM system showed about 5 dB net coding gain at 6.7% redundancy rate. RS (255,239) is standardized by ITU recommendations G.709/G.975 and also can be referred to in the literature as a standard FEC or generation one FEC.

To achieve higher coding gain different combinations of concatenated RS codes were tried, providing proper interleaving of outer and inner codes. These types of codes can generate higher gross coding gain of 8–10 dB compared to RS (255,239) but require higher overhead rate, 14–25%. These types of concatenated codes have been deployed commercially in several recent undersea systems and are referred to as super FEC or generation two FEC. One particular concatenated scheme considered here employs RS (223,207) outer and RS (255,223) inner interleaved codes, which provides about 9 dB gross coding gain for BER requirement of 1.0E-13 at the cost of 23% bit rate overhead.

Theoretical conversion formula for FEC encoding/decoding can be derived if the errors are assumed to be from additive white Gaussian noise. The OptSim BER Tester model block has implemented FEC conversion

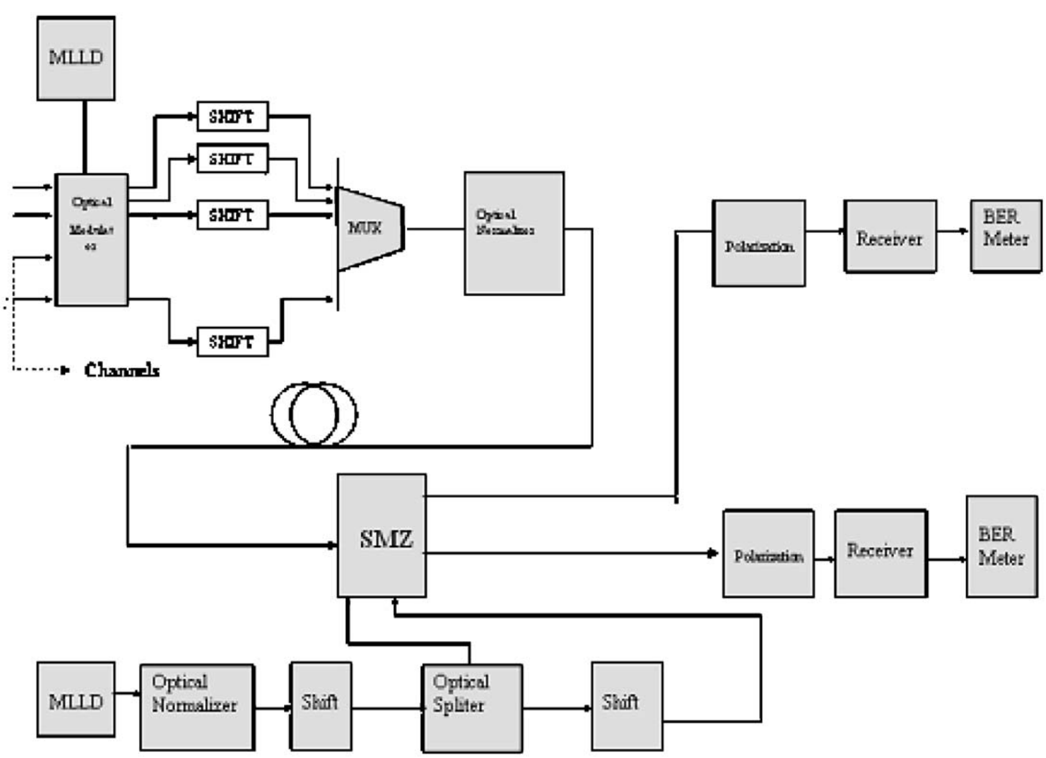


Fig. 1. System description.

formula for RS (255,239) and concatenated RS (223,207)/RS (255,223) codes.

It must be noted that this model does not actually decode the data but rather applies FEC coding gain to input BER according to the selected FEC scheme. Also note that the coding gain can be optimistic in cases with high PMD, where long periods of high error rates may degrade the error-correcting capability of the code.

2. System description

The proposed system is shown in Fig. 1. The transmitter is comprised of a pseudo random binary sequence or PRBS generator, a mode-locked laser diode or MLLD, an electrical generator, an array of time shifting blocks, an optical multiplexer, and an optical normalizer. Multiple channels from an MLLD are RZ modulated with different PRBS patterns. The PRBS block generates multiple pattern outputs, each different from the other and at same bit rate. All the channels from MLLD are at the same wavelength of 1550 nm and of same power. The pulse width of these channels can be modified in this block. Before being multiplexed together each consequent channel is delayed by $\frac{1}{4}$ of time window in succession. Total power of all the channels is controlled by an optical normalizer, which determines the average output power of OTDM signal before propagation over the fiber length. This is referred as Psignal in this project.

The control signal block consists of a pulse train generator (with same repetition rate as the transmitter), a pulse splitter, and two time delay blocks. The first time delay block will set the control signal to de-multiplex the channel of interest. The control signal splits in two parts before being coupled with data signal in two arms of SMZ. The second time delay signal sets switching window duration and is set to data pulse duration. Pulse width of the control signal is set to the same value as the transmitted channel. The power of the control signal is controlled by an optical normalizer block in this leg. This is referred to as Pcontrol in this project.

Table 1. Fiber parameters

Non-linear fiber parameter	Value
Length	75 km
Diameter	8.2 e–6 m
Aeff	1.425
Include_Spm	Yes
Include_xpm_el	Yes
Include_xpm_mol	Yes
n2	2.6e–20 m ∧ 2/w
Loss	0.25 db/km
Include dispersion	Yes

The state of polarization is set to be orthogonal to data signal.

The receiver block consists of an SMZ, and two outputs from SMZ are referred to as switching and reflecting ports. Symmetrical Mack–Zehnder interferometer consists of two 50/50 couplers, two multiplexers, and two SOAs. Signal data are injected to SMZ through the upper inputs. Optical signals from both ports then go through the linear polarizer blocks to separate control pulses from data. Inputs to receiver blocks will have only data signals. The receiver converts the optical signal into electrical signal (Table 1).

3. Results and discussion

The result of inclusion of FEC for channels 1and 2 has been shown in Fig. 2(a) and (b), respectively. Similarly, the inclusion of FEC for channels 3 and 4 has been shown in Fig. 3(a) and (b), respectively.

It can be clearly observed that there is a marked improvement in BER with FEC. In case of channel 1

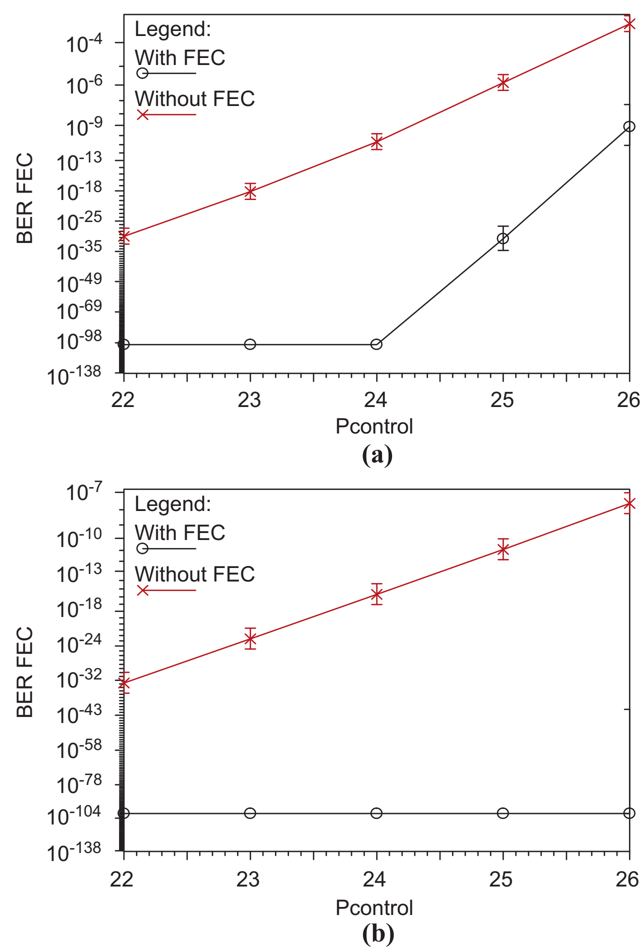
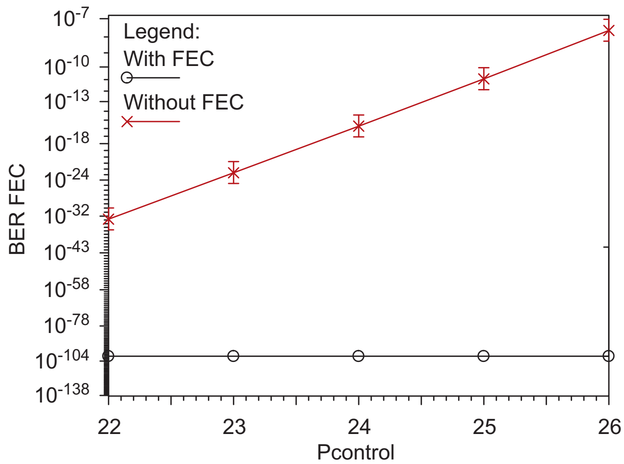


Fig. 2. Comparison of BER with and without FEC for channels 1 (a) and 2 (b), respectively.



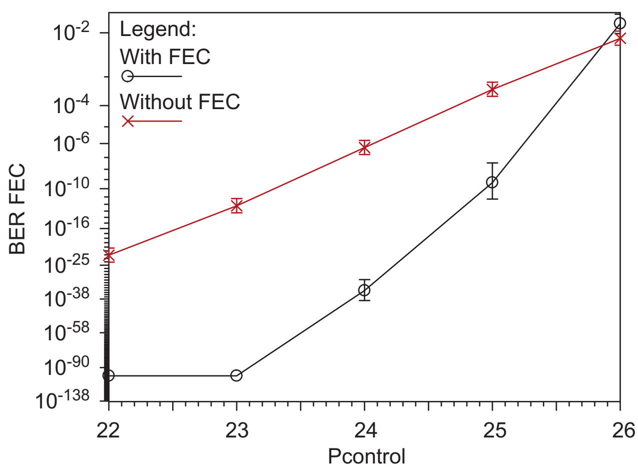


Fig. 3. Comparison of BER with and without FEC for channels 3 (a) and 4 (b), respectively.

BER falls from 10^{-30} to 10^{-98} and from 10^{-4} to 10^{-13} for Pcontrol values of 22 and 26, respectively. In case of channel 2 BER falls from 10^{-32} to 10^{-104} and from 10^{-6} to 10^{-104} for Pcontrol values of 22 and 26, respectively. In case of channel 3 BER falls from 10^{-32} to 10^{-104} and from 10^{-6} to 10^{-104} for Pcontrol values of 22 and 26, respectively. In case of channel 4 BER falls from 10^{-18} to 10^{-91} and increases from 10^{-2} to $10^{-3}$for Pcontrol values of 22 and 26. Once again the results show that channels 2 and 3 show identical behavior. It is interesting to note that for channels 2 and 3 the BER is constant in the Pcontrol range from 22 to 26.

4. Conclusion

The paper results show that the inclusion of FEC clearly indicates that there is reduction in BER in case of all the channels. Further it is observed that different channels exhibit different behaviors as regards the variation in Pcontrol values. It is concluded that inclusion of FEC in OTDM transmission can greatly improve the system performance.

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