Optical Error Correction using Passive Optical Logic Gates Demodulators in Differential Demodulation

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Abstract: We propose and demonstrate an error-correction technique with no overhead for differentially encoded modulation formats. The method improves FEC equipped systems, increasing chromatic dispersion tolerance by 25% while reducing the penalty of imperfect optical filtering.

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1. Introduction

Differential phase shift keyed transmission (DPSK) is currently under serious consideration as a deployable data-modulation format for high-capacity optical communication systems due mainly to its 3 dB OSNR advantage over intensity modulation [1-2]. Forward error correction (FEC) with 7% or 25% errors is now commonly used in long haul transmission systems. With only 7% of overhead, a $2e^{-3}$ error rate becomes $1e^{-15}$ while with a 25% overhead, error rate as low as $6e^{-3}$ can be corrected. Unfortunately when error rates are greater than those values, FEC becomes somewhat inefficient. An error correction technique for low error rates to complement FEC with no increase in required bandwidth would be of great interest.

In this paper we propose and demonstrate experimentally an optical multi-path error correction technique with no overhead for DPSK. By demodulating the received signal through three separate paths and applying a majority vote error correction on the three paths, error correction is achieved. The theoretical limit when the demodulation paths are completely independent allows a 1.2×10^{-2} error rate to become 2×10^{-3} suitable for eFEC or 2.1×10^{-2} to reach 6×10^{-3} suitable for Super FEC. In a back-to-back transmission, errors are somewhat correlated in each demodulation path such that the coding takes a 2.6×10^{-3} BER to a 2×10^{-3} BER and a 6.92×10^{-3} BER to a 6×10^{-3} BER. Transmission impairments and receiver degradations causes a decorrelation between demodulation paths. Simulations results show that CD tolerance is increased by 25% from ±1220 ps/nm to ±1520 ps/nm for a 3dB penalty. The method also increases the tolerance to improper optical and electrical filtering. We demonstrated the method experimentally and were capable of correcting an error rate of 5E-3 to 2E-3 for eFEC and of 1E-2 to 6E-3 for SuperFEC.. The scheme is also compatible with electronic compensation techniques.

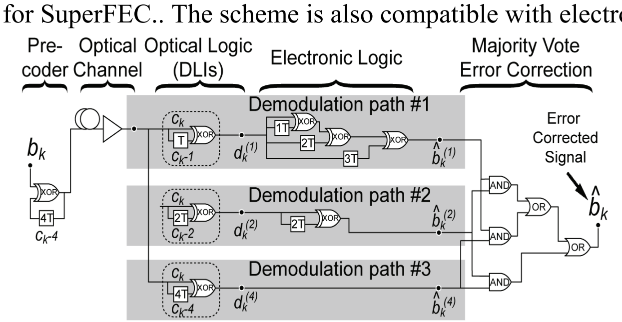

Figure. 1.Conceptual diagram of multipath demodulation with majority vote error correction. The DPSK precoder uses a 4-bit delay. Optical logic is done using passive DLI DPSK demodulator. The electronic logic recovers the original signal before majority vote is applied.

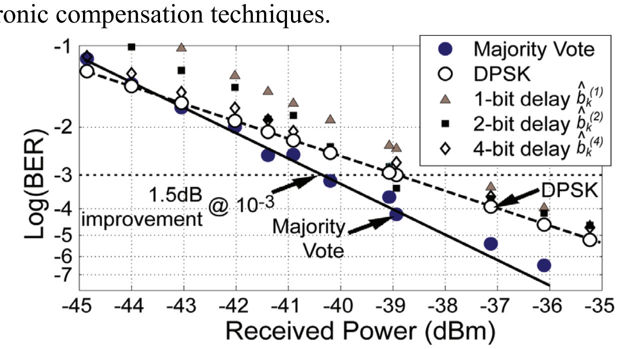

Figure 2. Experimental results for the 3 paths and the majority vote. A 1.5dB improvement is observed at BER 10^{-3} 5E-3 to 2E-3 for eFEC and of 1E-2 to 6E-3 for SuperFEC thus extending the efficiency of FEC without increasing the overhead

2. Concept and Theory

The scheme takes advantage of the combination of the optical logical XOR function of the DLI and electronic binary logic gates as illustrated in Fig. 1. Electronic 4-bit differential precoding is performed at the transmitter prior to optical modulation. Optical demodulation is performed using multiple demodulation paths each having a DLI

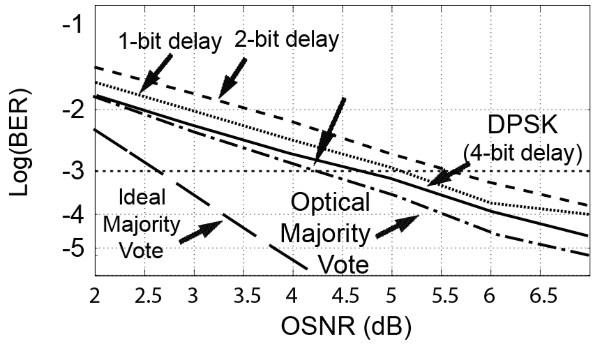

Figure 3. Back-to-back numerical results for the 1 bit-delay, the 2 bit delay and 4-bit delay paths and optical majority vote. Ideal majority vote performance when errors are uncorrelated is shown.

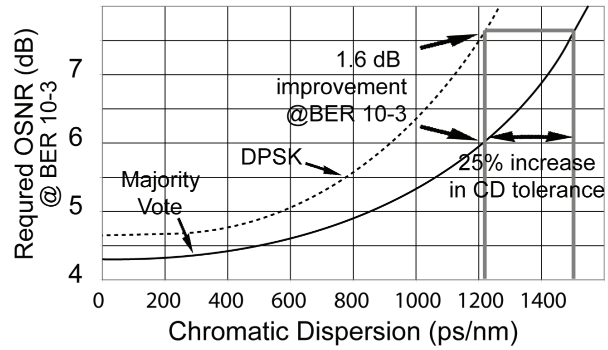

Figure 4. OSNR penalty versus CD for DPSK and majority vote demodulation. A 25% increase in CD tolerance for a 3dB OSNR penalty at BER $10^{-3}$is found.

with a different integer bit-delay similar to [3-4]. Electronic logical XOR gates are used to re-align the three paths together and error-correction is performed through a simple majority vote algorithm as illustrated in Fig.2.

3. Experimental and Numerical Results

We performed experimental verification using a 2^{15}-1 PRBS DPSK pattern at 10Gbps and DPSK demodulators from ITF Laboratories with 1 bit, 2 bits and 4 bits delays [5]. The three paths are detected simultaneously and sent into a 20Gsample/s real-time oscilloscope with memory for 500 000 bits in each path. The experimental BER improvement is illustrated on Fig.4. At a BER of 10-3, the back-to-back improvement is 1.5dB capable of correcting a 1e-2 BER down to 1e-3 where FEC can function effectively. Monte Carlo simulations using a 12.5 GHz optical filter and an 8 GHz electrical filtering at the receiver show an improvement in receiver sensitivity of 0.35dB at a BER of 10^{-3} in back-to-back configuration (Fig.3). The theoretical curve for a majority vote if the errors were uncorrelated explains the better experimental results. Non- ideal optical and electrical filtering in our experiment. Fig 5 and 6. illustrate the simulated contour plots of required OSNR versus optical and electrical filtering. With majority vote, the effect of optimized optical filtering is not significant.

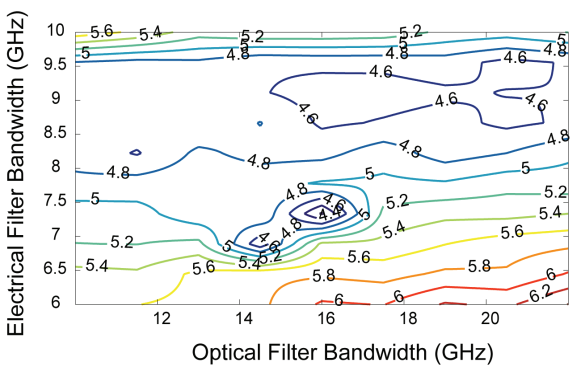

Figure 5. DPSK contour plot of required OSNR at BER 10-3 for electrical and optical filter bandwidth combination

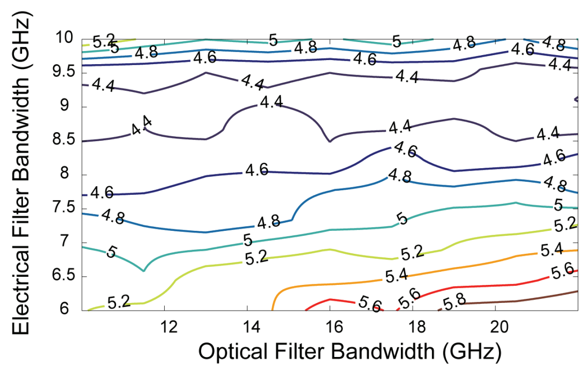

Figure 6. Majority vote multipath demodulation contour plot showing very good tolerance to optical filtering.

4. Chromatic Dispersion Sensitivity

Chromatic dispersion in the demodulated signal may leads to less correlated errors in each path. Such uncorrelated errors improve the performance of the method by bringing the correction efficiency closer to the theoretical limit illustrated in Fig. 3. Fig. 5 illustrates numerical results for CD sensitivity. The baseline curve matches previously reported results for CD tolerance for NRZ-DPSK and as expected, majority vote performs well with a 1.6 dB improvement at a BER of 10^{-3}. Chromatic dispersion tolerance with a 3dB penalty is increased by 25% from ±1220 ps/nm to ±1520 ps/nm.

5. References

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