NOISE SUPPRESSION IN OPTICAL COHERENT QPSK TRANSMISSION SYSTEMS USING AVERAGING FILTERS

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Introduction

Optical coherent Quadrature Phase Shift Keying (QPSK) transmissions can double the data rate of existing intensity modulation and direct detection (IM/DD) systems [Noe]. Coherent receivers have superior sensitivity and the transmission impairments (chromatic dispersion, polarization mode dispersion, noise) can be compensated in electronic domain at low speed [Pfau]. This paper models an optical coherent QPSK transmission system with Additive White Gaussian Noise (AWGN) and laser phase noise. The paper discusses low pass filtering methods with different filtering algorithms that reduce the effects of AWGN and laser phase noise [Noe, Pfau].

Methodology

The basic optical coherent QPSK transmission system was established in MATLAB and the AWGN and laser phase noise were added to the model. Transmitted bits and received bits after demodulation and decoding were compared to find Bit Error rate (BER). Filter parameters were modified to obtain optimum performance. Monte-Carlo simulation was used to obtain BER vs. OSNR (optical SNR) curve.

Modulation Scheme

Quadrature PSK (QPSK) uses four points on the constellation diagram, equispaced around a circle. With four phases, QPSK can encode two bits per symbol, with Gray coding to minimize the BER. BPSK transmit 1bit/symbol and 8-PSK transmit 3bit/symbol compared to QPSK.

Types of Noise in the Optical Transmission Systems

The following noise sources are playing major role in Optical Communication systems.

AWGN due to amplified spontaneous emission (ASE) in the receiver amplifier: ASE introduces noise and reduces the efficiency of the optical amplifier. The effect of the ASE at the receiver can be described by AWGN process.

Phase Noise: Phase noise occurs due to non-zero line width of the source and local oscillator lasers. The frequency shifts due to finite line width is modelled by a time varying phase. The time varying phase is modelled by a random walk process. Phase noise variance,

$$\sigma^2 = 2\pi * LW * R \quad (1)$$

Where, LW= 3 dB Laser Line width and R=Data rate

Data Recovery and Filtering

In the generated bit stream, every two consecutive bits are combined together to form symbols. The symbols are gray encoded to minimize bit errors. Generated quadrant numbers ($n_{d,p}$) are differentially encoded to form an differently encoded quadrant number ($n_{c,p}$), and transmitted through the channel [Noe].

$$n_{c,p}(i) = \left(n_{d,p}(i) + n_{c,p}(i-1)\right) \bmod 4 \quad (2)$$

In data recovery, fourth power of the received signal is taken to eliminate the QPSK modulation. Because,

$$\left(e^{j\frac{k\pi}{4}}\right)^4 = -1\text{, for } k \in Z. \quad (3)$$

The resulting frequency-quadrupled carrier components are added and then low pass filtered for further noise suppression. The sum is taken of most recent samples of the frequency-quadrupled carrier that is 2N+1, for a good average filtering. Filter function is given by,

$$Y(i) = \sum_{m=-N}^{+N} W_m (X(i-m))^4 \quad (4)$$

$$\textit{Where, } \sum_{m=-N}^{+N} W_m = 1$$

The phase angle is altered due to filtering; therefore phase should be divided by four to recover the original carrier phase (φ_p).

$$\varphi_p(i) = \left(1/_4\right) * arg(-Y(i)) \quad (5)$$

The received quadrant number $n_{r,p}(i)$ is obtained from equation (6).

$$n_{r,p}(i)\pi/2 \leq \Psi_p(i) - \varphi_p(i) < (n_{r,p}(i)+1)\pi/2 \quad (6)$$

Where, Ψ_p= Angle of the received signal

Practically the correct quadrant number cannot be selected within one symbol duration, because the carrier phase may be jumped to other quadrant. To determine whether φ_p has jumped by an integer multiple of $\pi/2$, a jump quadrant number (n_j) is selected according to equation (7).

$$|\varphi_p(i) - \varphi_p(i-1) - n_j(i)\pi/2| \leq \pi/4, \quad (7)$$

Since angle functions are periodic all quadrant numbers must be valid modulo4. Due to differential encoding at the transmitter side, the received signal is decoded to find an output quadrant number, which can be calculated as follows,

$$n_{o,p}(i) = \left(n_{r,p}(i) - n_{r,p}(i-1) + n_j(i)\right) \bmod 4 \quad (8)$$

Where $n_{o,p}$ = Output quadrant number

Weighted Viterbi &Viterbi algorithm explains how the Wiener filter can be optimized with variable weights and the optimal values for the Wiener coefficient v_n. The Weiner coefficient depends on variance ratio of laser-induced phase noise to the angular portion of AWGN ($\sigma_\Delta^2/\sigma_{n'}^2$) and it is defined as follows,

$$v_n = \frac{k}{1-k^2}\frac{\sigma_\Delta^2}{\sigma_{n'}^2}k^{|n|} \quad (9)$$

Where,

$$k = \left(1 + \frac{1}{2}\frac{\sigma_\Delta^2}{\sigma_n^2}\right) - \sqrt{\left(1 + \frac{1}{2}\frac{\sigma_\Delta^2}{\sigma_n^2}\right)^2 - 1}$$

σ_Δ^2 = Phase noise variance,,

$\sigma_{n'}^2$=AWGN variance and the sum of the Wiener coefficients (v_n) is

$$\sum_{-\infty}^{+\infty} v_n = 1$$

Simulation results

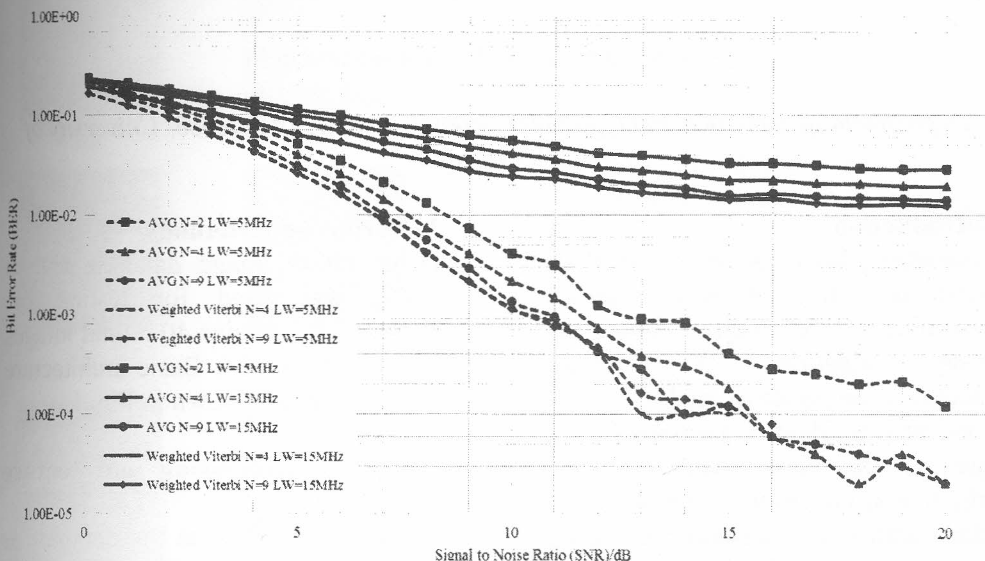

Fig. 1. BER vs. SNR curves of all filters for different Laser Line Widths (LW)

Discussion

Considering the limitation in the performance of the computer less number of bits (10^5) was used for simulation. When the signal is transmitted through the fibre optics Laser phase noise and Gaussian noise are added to the original signal. Because of the influences of these noises bit errors occur at the receiver. To filter the noise component added during transmission different filters are used. The performances of the filters are measured by means of BER vs. SNR curves. From the simulation results (Fig. 1.) it can be seen that BER increases when the laser line width is increased and BER decreases when the filter width is increased for all filters. But, the filter made using weighted Viterbi & Viterbi algorithm gives better performances than others.

Conclusion

Average filter gives acceptable BER for low phase noise. But, when the phase noise level is high, it can be recommended to go for the filter, which uses weighted Viterbi & Viterbi algorithm.

References

Noe, R. (2005).PLL-Free Synchronous QPSK Polarization Multiplex/ Diversity Receiver Concept with Digital I&Q Baseband Processing IEEE Photonics Technology Letters, vol. 17, NO. 4.

Pfau, T.(2009).Algorithm development for coherent digital receivers and simulation and real-time imple- -mentation of coherent optical transmission systems, PhD Thesis, University of Paderborn.