Accurate bit error rates from multicanonical Monte Carlo simulations

R. Holzlöhner and C. R. Menyuk

Department of Computer Science and Electrical Engineering,
University of Maryland Baltimore County,
TRC 201 B, 1000 Hilltop Circle, Baltimore, MD 21250
phone: 410-455-3318, fax: 410-455-6500, email: holzloehner@umbc.edu
http://www.photonics.umbc.edu/

Abstract: We apply the multicanonical Monte Carlo method to compute bit error rates and eye diagrams in a chirped return-to-zero (CRZ) system. Our results agree with the covariance matrix method over 20 orders of magnitude.

OCIS codes: (060.0060) Fiber optics communications; (270.2500) Fluctuations, relaxations, and noise

The traditional way of computing bit error rates (BERs) and eye diagrams is to run Monte Carlo simulations. This method leads to large statistical fluctuations in the tails of the probability density function (pdf) and is hence inefficient. As a consequence, system designers often use a simplified approach in which they assume that the optical noise spectrum at the receiver is white, effectively neglecting the nonlinear signal-noise interaction. This simplification is inappropriate for long-haul optical communications systems. The covariance matrix method [1], [2] does take into account the nonlinear signal-noise interaction and works for nonlinear systems. However, it can fail when the optical noise-noise interaction becomes large.

In this contribution, we apply the multicanonical Monte Carlo (MMC) simulation technique that was pioneered by Berg, *et al.* [3], [4]. Recently, the MMC method has been successfully used to compute PMD emulator statistics [5]. MMC is closely related to importance sampling [6] in the sense that both methods increase the number of events in the tail region of the pdf by biasing them. The principal advantage of MMC is that it does not require the scientist to guess a suitable bias. Instead, it converges automatically to the optimal bias.

Our simulated transmission line is identical to [2] and consists of 34 dispersion maps each of length 180 km for a total distance of 6,120 km. Every 45 km, the loss is compensated by an EDFA with a spontaneous emission factor of $n_{\text{sp}} = 2.0$. The signal pulses are co-polarized and have an initial full width at half maximum (FWHM) duration of 28 ps with a chirped raised-cosine shape. We transmit a pseudorandom bit sequence of $2^5 = 32$ bits, exhausting all possible bit patterns of length 5. At the receiver, we simulate a 40 GHz optical filter, followed by an ideal square law detector and a 7 GHz 5-th order Bessel filter.

Fig. 1 shows a comparison of the pdfs of the receiver voltage based on 50,000 MMC noise realizations (crosses and circles) and the pdfs obtained from the covariance matrix method (solid curves). The voltage is normalized to the noise-free peak voltage of the 32-bit signal. The pdf of the marks and the spaces are averaged over all 16 marks and 16 spaces, respectively, and correspond to the centers of the bit slots. The agreement between the covariance matrix method and the MMC results is excellent over a range of 20 orders of magnitude.

In summary, we applied the multicanonical Monte Carlo (MMC) method to compute bit error rates and eye diagrams in a chirped return-to-zero (CRZ) system over 6,100 km. Our results agree with the covariance matrix method over 20 orders of magnitude, validating its use for this system. We conclude that MMC is an important tool in simulating optical communications systems. In principle, it is completely accurate, and it allows the user to validate simplified approaches that are less computationally time-consuming.

References

1. R. Holzlöhner, C. R. Menyuk, V. S. Grigoryan, and W. L. Kath, "Accurate calculation of eye diagrams and error rates in long-haul transmission systems," In *Proc. OFC'01*, talk MF3 (Anaheim, CA, 2001).
2. R. Holzlöhner, C. R. Menyuk, W. L. Kath, and V. S. Grigoryan, "Efficient and accurate calculation of eye diagrams and bit-error rates in a single-channel CRZ system," IEEE Photon. Technol. Lett. **14,** 1079–1081 (2002).
3. B. A. Berg and T. Neuhaus, "Multicanonical algorithms for first order phase transitions," Phys. Lett. B **267,** 249–253 (1991).
4. B. A. Berg, "Algorithmic aspects of multicanonical Monte Carlo simulations," Nucl. Phys. Proc. Suppl. **63,** 982–984 (1998), hep-lat/9708003.
5. D. Yevick, "Multicanonical communication system modeling — application to PMD statistics," IEEE Photon. Technol. Lett. **14,** 1512–1514 (2002).

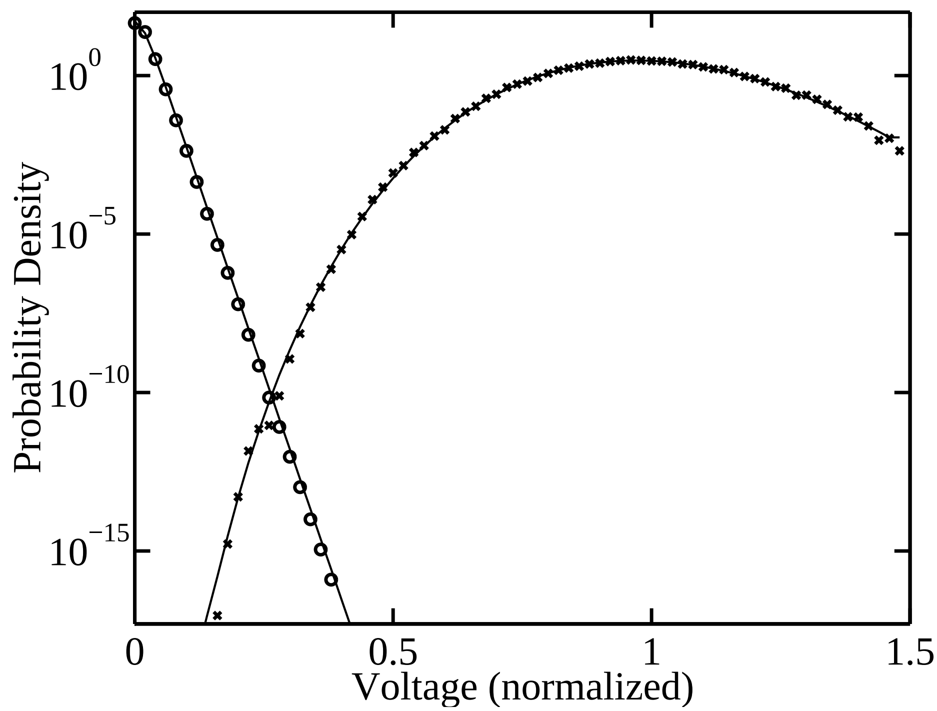

Fig. 1. The pdf obtained from a multicanonical Monte Carlo simulation in the marks (crosses) and the spaces (circles) versus the pdf from the covariance matrix method [1], [2] (solid curves).

6. G. Biondini, W. L. Kath, and C. R. Menyuk, "Importance sampling for polarization-mode dispersion," IEEE Photon. Technol. Lett. **14,** 310–312 (2002).