

Probability of error in high bit rate optical fiber transmission systems

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Summary

In high bit rate optical fiber transmission systems, the non-linear nature of optical fiber becomes a major obstacle for reliable transmission. We have derived probability density functions for errors in such systems.

Optical fiber communication is a key component of the “information revolution”. Due to its huge natural bandwidth and low loss, an optical fiber is capable of keeping up with growing bandwidth demand. Because of this property, optical fiber is of crucial importance for next generation communication systems. Increase in information transmission rate introduces a new factor that limits system capacity. Fiber non-linearity is one of the key limitation factors and makes these limits difficult to calculate.

Dispersion management is the most promising technology for high rate optical transmission systems. It consists of alternating spans of optical fiber with opposite sign of chromatic dispersion. While propagating through a fiber, a pulse experiences broadening. This broadening is due to the fact that different frequency components propagate with different velocities. The process of broadening changes to compression when the pulse enters into a span with opposite chromatic dispersion. In a data stream, as nearby pulses broaden, they begin to overlap with their neighbors, and four-wave mixing and other nonlinear processes occur. The most malign effect of this nonlinear interaction is the generation of *ghost pulses*,

which are pulses that form in time slots which initially contain no pulse. The process of ghost pulse generation depends on the bit pattern and noise coming from optical amplifiers. After propagating a certain distance, a ghost pulse in a “0” slot, coupled with noise, may contain enough energy to register as a “1” at the receiver, producing an error.

Using methods of modern statistical physics and computer simulations, we studied the process of ghost pulse generation, as well as attrition of original pulses. Figures 1a and 1b show an example of distribution of ghost pulse energy (for a given set of parameters) in logarithmic and linear scales.

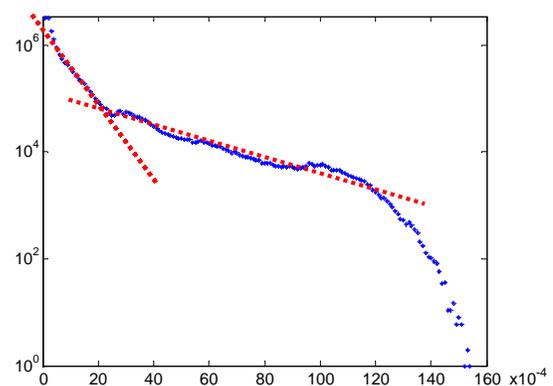


Figure 1a: Energy of a ghost pulse versus number of bit configurations that give that energy

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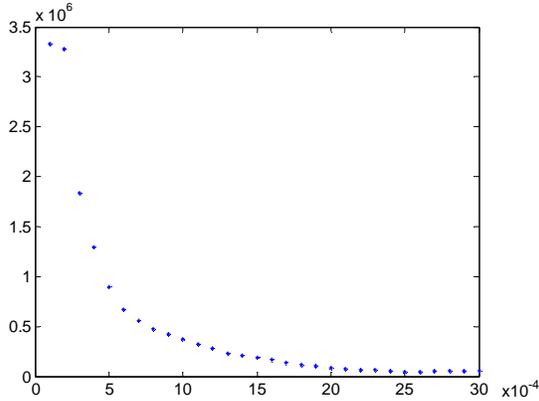


Figure 1b: Energy of a ghost pulse versus number of bit configurations that give that energy

It can be seen that the distribution of energy is non-Gaussian and has exponential central part up to 3×10^{-4} and exponential extended tail up to approximately 125×10^{-4} . The exponential nature is pointed out by two straight lines in Figure 1a.

The most probable energy values are also presented in Fig 1b, where the exponential nature is even more pronounced.

The bit configurations that are most likely to be corrupted, those on the far right of Figure 1a, were identified. We show the worst five bit configurations:

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011110101111 0 111101011110
001110101111 0 111101011110
011110101111 0 111101011100
001110101111 0 111101011100
011110101111 0 111100011110
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Similar results are obtained for bit configurations with “1” at the center slot. It turns out that the effect is much less malign in this case.

Noise is another very important limiting factor. Using the *instanton approach*, we derived probability density functions for the energy of a given bit configuration coupled with noise.

These probability density functions turn out to be exponential also, not Gaussian, as is often assumed.

As an illustration, in Figure 2 we present the probability density function for bit error rate, for bit sequences with “1” at the center slot (for a specific set of parameters).

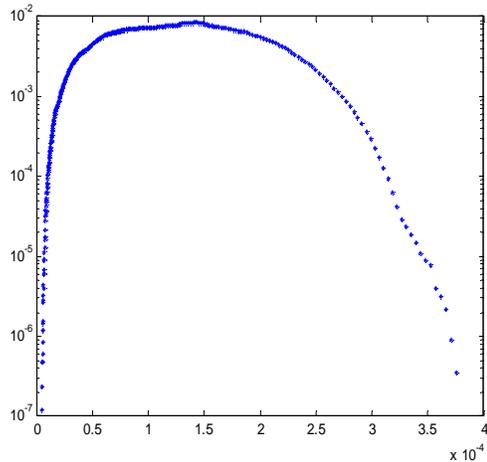


Figure 2: Probability density function for bit error rate, for bit sequences with “1” at the center slot

It is important to note that non-linear effects and noise cannot be treated separately.

In conclusion, we have developed a technique for assessing the reliability of future optical fiber transmission systems and offered suggestions about how reliability can be improved. Improvement will come from identifying (and/or designing) error correction codes that are most suitable for use in these systems, *i.e.* those codes that are capable of treating, or avoiding, bit configurations that are most likely to lead to an error.

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