BER of Optical Communication System using Fiber Source

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Abstract — We analyze the bit-error rate (BER) of an optical communication system using the superfluorescent fiber source (SFS). The counting statistics of thermal light give improved performance relative to the Gaussian statistics that predict a BER floor.

SUMMARY

Consider a spectrum-sliced wavelength-division multiple-access (WDMA) system that employs the SFS [1]. In the SFS, spontaneous atomic emission is amplified through a rare-earth doped, single mode, optical fiber end-pumped by an external laser. The incoherent, broad bandwidth output is best modeled as thermal light. The output is spectrum-sliced then on-off modulated by a binary symbol stream, resulting in an intensity modulation waveform arriving at the photodetector. Neglecting the dark current and thermal noise, we obtain the BER as the Laplace transform of the integrated intensity W :

$$BER = \frac{1}{2} \int_0^\infty e^{-\alpha w} p_W(w) dw, \quad (1)$$

where $p_W(w)$ models the stochastic fluctuation of the light, $\alpha = \eta/h\nu$ (η is the quantum efficiency and $h\nu$ the photon energy). Using the negative binomial statistics for the photoelectron count [2], the BER and the signal/noise ratio are:

$$BER = \frac{1}{2} \left[1 + \frac{\eta P}{P_c} + \left(\frac{\eta P}{2P_c} \right)^2 (1 - \mathcal{P}^2) \right]^{-M}, \quad (2)$$

$$SNR = \frac{M}{P_c/\eta P + .5(1 + \mathcal{P}^2)}. \quad (3)$$

The mode number, M , is the ratio of the symbol duration T to the coherence interval T_c of the incident light. That is, $M = B_o/2B_e$, where $B_o = 1/T_c$ and $B_e = 1/2T$ are the optical and detection bandwidths, respectively. $P = E[W]/T$ is the received power, $P_c \triangleq h\nu/T_c$ is the coherence power of the photon and $\mathcal{P}$ the degree of polarization. The limiting SNR is $B_o/(1 + \mathcal{P}^2)B_e$ for high received power ($\eta P/P_c \gg 1$).

The BER approaches the shot-noise limited value of $.5e^{-\alpha E[W]}$ if the count degeneracy parameter, $\eta P/P_c$, is much smaller than unity. Since the BER decreases monotonously with T_c , a Lorentzian spectral shape can have a lower BER at a higher symbol rate compared to a Gaussian shape with the same power and 3 dB linewidth. The ideal rectangular linewidth has the worst performance. This must be considered against the channel crosstalk since, not surprisingly, the tail of a Lorentzian has the slowest spectral decay. Without the linewidth constraint, we obtain a rather interesting theoretical result that the shot-noise performance is achieved with a spectral shape of infinite linewidth and zero spectral height. In comparison, this is also achieved with an ideal, coherent laser of zero linewidth and infinite spectral height.

In spectrum-sliced WDMA, the maximum SNR is inversely proportional to the number of channels. Equation (2) demonstrates that the BER is not determined solely by the SNR which reaches a limiting value; increasing the spectral intensity of the light reduces the BER. In fact, the number of channels can be increased by increasing the received power, while maintaining a desired BER for a given symbol rate. This has important implications for spectral amplitude encoded CDMA systems that require a large number of spectral chips [3]. Invoking the Gaussian assumption [1] would lead to incorrect conclusions. For example, the Gaussian predicts a BER floor due to the limiting SNR and therefore expects that it would be impossible to increase the number of channels by increasing the power, once the limiting SNR has been reached.

One can show that the BER is lower bounded by using the fact that $e^{-\alpha w}$ is convex over $[0, \infty)$ and applying Jensen's inequality to Eq. 1 to obtain $BER = .5E[e^{-\alpha W}] \geq .5e^{-\alpha E[W]}$. Accordingly, a light source that achieves this can be considered ideal, i.e. its intensity is deterministic: $p_W(w) = \delta(w - E[W])$, as would be expected. Figure 1 shows calculated BER values for the ideal and spectrum-sliced fiber sources, and the Gaussian assumption. The Gaussian predicts a BER floor and underestimates the true performance.

Fig. 1: BER comparisons at 1 Gbps. The spectrum-sliced SFS is polarized ($\mathcal{P} = 1$); $M = 36$, $\eta = 50\%$ at 1550 nm wavelength.

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