Quantum Illumination by Quasi-Bell States with Thermal Noise

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Abstract. Quantum illumination is one of the application protocols of entanglement. This protocol uses entanglement for the target detection. Entangled states by nonorthogonal states, such as coherent states, are called "quasi-Bell states". These states are expected to be robust against attenuation. In our previous study, we investigated the effect of attenuation on this protocol using a quasi-Bell state. In this paper, we consider the error probability when assuming a communication channel that has thermal noise in addition to attenuation.

Keywords: Entanglement, Quantum Illumination, Quasi-Bell State

1 Introduction

Quantum illumination uses entangled light of two-mode. To decide whether the target is present or absent, one of the two modes is emitted toward the target. This protocol was first proposed by Lloyd in 2008 [1] as an application of the Bell state. Moreover, the application of the two-mode Gaussian state has been considered [2]. In previous research [3], we investigated the error performance using the quasi-Bell states, which dealt with the most basic attenuated channel. In this study, we consider the error probability when assuming a communication channel that has thermal noise in addition to attenuation.

2 Quasi-Bell states

In this study, we consider the entangled coherent states as a quasi-Bell states. Using two coherent states $|\alpha\rangle_{\mathrm{S}}$ and $|\beta\rangle_{\mathrm{I}}$, the quasi-Bell states are

$$|\Psi_1\rangle = h_1(|\alpha\rangle_{\mathrm{S}}|\beta\rangle_{\mathrm{I}} + |-\alpha\rangle_{\mathrm{S}}|-\beta\rangle_{\mathrm{I}}), \quad (1)$$
$$|\Psi_2\rangle = h_2(|\alpha\rangle_{\mathrm{S}}|\beta\rangle_{\mathrm{I}} - |-\alpha\rangle_{\mathrm{S}}|-\beta\rangle_{\mathrm{I}}). \quad (2)$$

If $\alpha = \beta$, then $|\Psi_2\rangle$ has maximum entanglement.

3 Results

We consider the joint measurement that minimizes the error probabilities. The *a priori* probabilities of the received quantum states $\rho_0^{(\mathrm{S}\otimes\mathrm{I})}$ (target absent) and $\rho_1^{(\mathrm{S}\otimes\mathrm{I})}$ (target present) are assumed to be equal. Fig. 1 shows the error probabilities using the non-maximum quasi-Bell states $(|\Psi_1\rangle, \alpha = \beta)$ and the maximum quasi-Bell states $(|\Psi_2\rangle, \alpha = \beta)$ when the transmissivity varies from 0 to 1, the average number of photons of signal light $N_{\mathrm{S}} = 0.5$, and the average number of thermal noise photons $N_{\mathrm{B}} = 0, 0.1$, and 1. From this figure, the error probabilities increase, as the average number of thermal noise photons N_{B} increases.

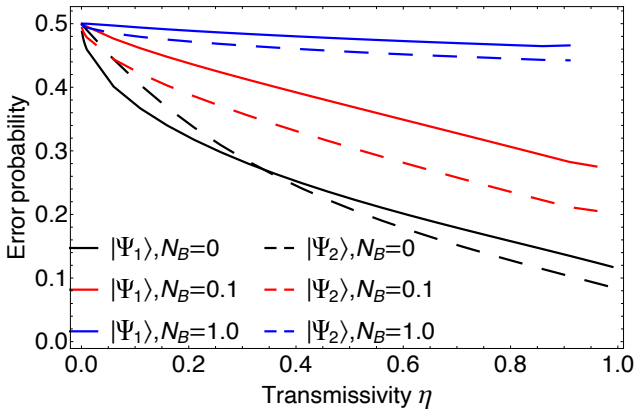

Figure 1: Error probabilities using the non-maximum quasi-Bell states $(|\Psi_1\rangle, \alpha = \beta)$ and the maximum quasi-Bell states $(|\Psi_2\rangle, \alpha = \beta)$, where the average number of photons of signal light $N_{\mathrm{S}} = 0.5$.

4 Conclusion

In this study, we evaluated the error performance using quasi-Bell states. As a result, thermal noise reduces the robustness against attenuation of quantum illumination.

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