Characterising linear optical networks with decoy-state techniques

Álvaro Navarrete,[1] Wenyuan Wang,[2] Feihu Xu,[3] and Marcos Curty[1]

[1]*EI Telecomunicación, Departamento de Teoría de la Señal y Comunicaciones, University of Vigo, Vigo E-36310, Spain*
[2]*Center for Quantum Information and Quantum Control, Department of Electrical and Computer Engineering and Department of Physics, University of Toronto, Toronto, Ontario, M5S 3G4, Canada*
[3]*Research Laboratory of Electronics, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, Massachusetts 02139, USA*

We present a general technique to characterise the behaviour of linear optical networks on input signals which are tensor products of Fock states. That is, our method allows us to estimate the probability distribution $\mathrm{P}(x_1,...,x_M|n_1,...,n_N)$ that describes the behaviour of the network on the input states $|n_1,...,n_N\rangle$. Here, n_i and x_j, with $i = 1,...,N$ and $j = 1,...,M$, denote, respectively, the number of photons at the input port i and at the output port j of the network. Importantly, our technique is simple and practical, and can be implemented with laser sources that generate quantum signals which are diagonal in the Fock basis in combination with threshold single-photon detectors. That is, our method does not require the use of expensive and complicated resources like deterministic multi-photon Fock state sources producing a fixed number of photons or photon number resolving detectors.

The key idea builds on two techniques that are commonly used in the field of quantum communication: the decoy-state method [1–3] and the so-called detector-decoy technique [4, 5]. We use the former at the input ports of the network, while the later is employed at its output ports. Specifically, we use Fock diagonal states with different photon-number statistics as input signals. These states can be generated with laser sources preparing phase-randomised weak coherent pulses together with variable attenuators. At the outputs ports of the network, we also place variable attenuators to implement the detector-decoy technique. In so doing, we have that for each possible detection pattern observed on the threshold single-photon detectors (located at the output ports of the network) we can write a set of linear equations of the form

$$\mathrm{P}^{\gamma,\omega}_{\boldsymbol{\theta}} = \sum_{\mathbf{n}} \sum_{\mathbf{x}\leq\mathbf{n}} \mathrm{P}^{\gamma}_{\mathbf{n}} \mathrm{P}(\mathbf{x}|\mathbf{n}) \mathrm{P}^{\omega}(\boldsymbol{\theta}|\mathbf{x}). \tag{1}$$

Here, $\mathrm{P}^{\gamma,\omega}_{\boldsymbol{\theta}}$ denotes the probability of observing a certain detection pattern $\boldsymbol{\theta}$ on the detectors; this probability is directly accessible in an experiment and only depends on the decoy-state and detector-decoy settings γ and ω, respectively, which are selected each given time. $\mathrm{P}^{\gamma}_{\mathbf{n}}$ is the probability that the input state to the network is the Fock state $|n_1,...,n_N\rangle$. This probability is priori-known and only depends on the setting γ. Finally, $\mathrm{P}^{\omega}(\boldsymbol{\theta}|\mathbf{x})$ represents the conditional probability to obtain the detection pattern $\boldsymbol{\theta}$ given that the input state to the detectors is the Fock state $|x_1,...,x_M\rangle$. This probability is also priori-known and only depends on the setting ω. Then, by solving the set of linear equations given by Eq. (1) one can in principle estimate any conditional probability $\mathrm{P}(x_1,...,x_M|n_1,...,n_N)$. To illustrate the practicality of this method, below we present a particular example. We obtain the conditional probabilities of a beamsplitter given the input state $|3,3\rangle$ and simulate the generalized HOM dip [6] in Fig. 1.

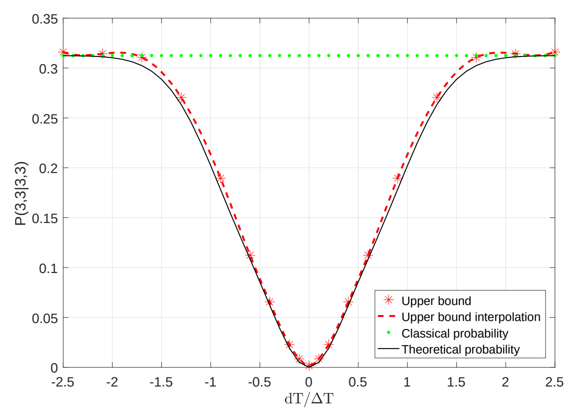

FIG. 1: Probability of obtaining three photons at each output of a beamsplitter with transmittance $\eta = 1/2$ given that the input state is $|3,3\rangle$. It is represented as a function of the relative delay $\mathrm{dT}/\Delta\mathrm{T}$, where dT denotes the delay between the two input ports of the beamsplitter and $\Delta\mathrm{T}$ the width of the pulses.

[1] W.-Y. Hwang, Phys. Rev. Lett. **91**, 057901 (2003).
[2] H.-K. Lo, X. Ma, and K. Chen, Phys. Rev. Lett. **94**, 230504 (2005).
[3] X.-B. Wang, Phys. Rev. Lett. **94**, 230503 (2005).
[4] T. Moroder, M. Curty, and N. Lütkenhaus, New J. Phys. **11**, 045008 (2009).
[5] A. R. Rossi, S. Olivares, and M. G. A. Paris, Phys. Rev. A **70**, 055801 (2004).
[6] Z. Y. Ou, *Multi-photon quantum interference*, 1st ed. (Springer, 2007).