Optimization of periodic single-photon sources based on combined multiplexing

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Single-photon sources play an important role in optical quantum information processing as well as in quantum optics. Recently, a great attention has been paid to the construction of heralded single-photon sources (HSPS) based on correlated photon pair generation in nonlinear optical media including spontaneous four-wave mixing (SFWM) in optical fibers and spontanteous parametric down-conversion (SPDC) in bulk crystals and waveguides. The latter process can provide highly indistinguishable single photons in an almost ideal single mode with known polarization [1–3]. Unfortunately, due to the probabilistic nature of pair generation there remains a finite probability of generating either more than one or no photon pairs during an expected heralding event. Two suggested ways can be found in the literature for overcoming this issue: spatial multiplexing [4–7] and time multiplexing[8–11]. Thus far only spatial multiplexing has been demonstrated experimentally [6, 7].

In Ref. [12] we introduced a theoretical framework that describes all spatial and time multiplexed single-photon sources realized or proposed thus far. This statistical description takes into account all the possible, relevant loss mechanisms. It was shown, that multiplexed sources can be optimized to reach maximal single-photon probability. This can be achieved by the appropriate choice of the number of multiplexed units of spatial multiplexers or multiplexed time intervals and the input mean photon number. Furthermore, a novel time-multiplexed scheme was proposed, that can be realized in bulk optics. This system could provide a single-photon probability of 85% with a choice of experimental parameters which are feasible according to the experiments known from the literature.

In this communication we show that multiplexed sources can be further enhanced to approximate better an ideal deterministic source. In order to increase the single-photon probability, we consider combined multiplexing, when the output of several time multiplexed SPDC sources are multiplexed spatially. This idea was originally proposed in Ref. [13]. We considered all promising time-multiplexed single-photon sources including high finesse photon storage cavity-based multiplexers and the bulk time multiplexer proposed in our previous work [12]. Spatial multiplexing can be realized through electronically controlled photon routers. The prevalently available routers have two input ports. Thus a single router is capable of merging two time-multiplexed SPDC sources, which leads us to a cascaded scheme. Beside the standard system we present a novel spatial multiplexer that can be realized in bulk optics. This system can have maximal transmission coefficient that can be achieved by current experimental techniques, though the value of this coefficient depends on the positions of the input ports.

We show through Monte Carlo simulations that combined multiplexing systems can be optimized in order to produce maximal single-photon probability for various sets of loss parameters by the appropriate choice of the number of spatially multiplexed time multiplexers, the number of multiplexed time intervals and the input mean photon pair number. Our analysis proves that combined multiplexing is a possible way of increasing single-photon probability. Approximately 90% single photon probability can be achieved with different combined systems using the proposed spatial multiplexer with the choice of feasible experimental parameters in the whole system.

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