Classical capacity of quantum Gaussian codes without a phase reference: when squeezing helps [1]

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Abstract. We study the rate of classical-information transmission using quantum Gaussian states without a phase-reference frame. We consider a family of phase-noise channels with a finite decoherence time, such that the phase-reference is lost after m uses. We show that the optimal Gaussian encoding is generated by a Haar-random passive interferometer acting on pure product states. We upper- and lower-bound the optimal coherent-state rate and exhibit a lower bound to the squeezed-coherent rate that, for the first time to our knowledge, surpasses any coherent encoding for m=1 and provides a considerable advantage with respect to the coherent-state lower bound for m>1.

Keywords: Classical communication on quantum channels, Phase-noise, Gaussian states, Squeezing

The possibility of maintaining a shared reference frame [2] between the sender and the receiver is often assumed a priori in analysing communication scenarios. This is the case for long-distance optical-fiber and free-space communication, where the information is encoded in quantum states of the electromagnetic field [3] and transferred through a quantum Gaussian channel, such as attenuation or additive noise [4]. For these channels it is well known that the maximum classical-information transmission rate is attained by sending coherent states [5], provided that the sender and the receiver can maintain a phase reference. However, standard phase-alignment and communication strategies can be seriously affected or even entirely ruled out by phase-noise [6-8].

In this work we consider a non-Gaussian memory channel for which complete phase-decoherence takes place after m subsequent uses of the transmission line, which effectively models the loss of a common phase reference within a finite time period. We characterize the structure of optimal Gaussian encodings, showing that the optimal rate is attained by producing pure product states and randomizing them with passive interferometers (PIs). In particular, the optimal coherent-state encoding modulates the total energy of the signals, which is then distributed randomly among all communication modes by the PIs. Hence, our result implies that the strategy of using part of the energy for preparing a phase-reference state in one mode and using the other modes to communicate is in general suboptimal, even at large energies.

Moreover, we show that squeezed-coherent states can be used to attain a larger communication rate with respect to simple coherent-state strategies. Interestingly, at variance with phase-estimation metrology [9], where improvements are typically obtained using signals with super-Poissonian photon-number statistics, the advantage we report here is obtained by trading coherent signals, characterized by Poissonian photon-number distribution, for sub-Poissonian squeezed-coherent states.

In the case m=1 we show that there exists a range of energies where an explicit on/off encoding, employing vacuum and a squeezed-coherent state, plus photodetection is provably better than any coherent-state encoding under the same energy constraint. Our result vindicates the optimality of non-classical Gaussian light in a physically-motivated communication context, in spite of the optimality of coherent-state encodings for common attenuator and additive-noise channels.

The enhancement of the communication rate carries over to the case m>1, although the explicit on/off strategy is not able to surpass the coherent-state upper bound. However, on the basis of the strong improvement that squeezing gives to the coherent-state lower bound, we conjecture that using squeezing is beneficial even for arbitrary values of m.

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