Phase Coherence in Quantum Metrology and Communication

Abstract

Quantum metrology and classical communication over quantum channels are quickly developing fields of science at the intersection of physics, statistics and information theory. One of the main problems in those theories is to understand the impact of phase coherence on performance of parameter estimation and information transmission tasks. Usually, the phase coherence is lost due to environmental noise and detection imperfections which are inevitable in any experimental realization. Particularly interesting both from scientific and technological point of view is the description of realistic situations in which loss of phase coherence, or more generally decoherence, is usually uncorrelated or measurement schemes are limited to a narrow class of experimentally realizable detectors.

In this thesis we have considered the influence of decoherence on the behavior of precision of parameter estimation in the asymptotic limit of large number of particles. We have shown that in the presence of uncorrelated decoherence precision in the Bayesian approach is asymptotically equivalent to precision in the local approach. On the hand, in the noiseless case there is a discrepancy between results of those two approaches and it is present irrespectively of prior knowledge about the parameter. We have shown also how to efficiently perform optimization of the local and Bayesian precisions over quantum states for moderate and large number of particles in the presence of decoherence.

We have discussed realistic protocols of information transmission using optical sources in the weak signal power regime in which quantum effects become dominant. We have shown for two realistic protocols that in the presence of losses using non-classical states of light gives only a small improvement in the communication rate attainable with photodetection over the best possible with classical states. Additionally we have shown that if we employ a collective detection scheme based on a linear optics circuit and photodetection then even if the phase of binary coherent states used for the communication fluctuates we can still attain communication rate scaling as in the noiseless scenario.

We have also pointed out similarities and discussed relations between crucial quantities from quantum estimation and communication theories. Unlike the previous works which were focused on the connection with Bayesian approach to estimation, we have found a relationship between information transmission rate and precision of a parameter estimation in the local approach which holds for narrow prior distributions. This enabled us to analyze issue of superadditivity in communication from the point of view of estimation theory.