1.3.14 Open quantum systems: theoretical characterization and experimental proposals

One of the major achievements of the recently emerged quantum information theory is the introduction and thorough investigation of the notion of quantum channel which is a basic building block of any data-transmitting or data-processing system. This development resulted in an elaborated structural theory [1] and was accompanied by the discovery of a whole spectrum of entropic quantities, notably the channel capacities, characterizing information-processing performance of the channels. The activity of the group in this field covers different research lines which are briefly summarized in the following.

In a series of theoretical papers [2,3,4] we studied the properties of open quantum system dynamics by adopting a collisional model. In particular in [2,3] we derived the general form of a master equation describing the interaction of an arbitrary multipartite quantum system, consisting of a set of subsystems, with an environment, consisting of a large number of sub-envirobments. Each subsystem "collides" with the same sequence of sub-environments which, in between the collisions, evolve according to a map that mimics relaxations effects. No assumption was made on the specific nature of neither the system nor the environment. In the weak coupling regime, we it was shown that the collisional model produces a correlated Markovian evolution for the joint density matrix of the multipartite system: the associated Linblad super-operator contains pairwise terms describing cross correlation between the different subsystems. In Ref. [4] we generalized the above analysis to include also quantum non-Markovian dynamics. In this case we endow the bath with memory by introducing inter-ancillary collisions between next system-ancilla interactions. Our model interpolates between a fully Markovian dynamics and the continuous interaction of the system with a single ancilla, i.e., a strongly non-Markovian process. We show that in the continuos limit one can derive a general master equation, which while keeping such features is guaranteed to describe an unconditionally completely positive and trace-preserving dynamics. We apply our theory to an atom in a dissipative cavity for a Lorentzian spectral density of bath modes, a dynamics which can be exactly solved. The predicted evolution shows a significant improvement in approaching the exact solution with respect to two well-known memory-kernel master equations.

In Ref. [5] we introduced a way to quantify the noise level associated to a given open quantum system transformation. The key mechanism lying at the heart of the proposal is "noise addition": in other words we compute the amount of extra noise we need to add to the system, through convex combination with a reference noisy map or by reiterative applications of the original map, before the resulting transformation becomes entanglement-breaking. We also introduce the notion of entanglement-breaking channels of order n (i.e. maps which become entanglement-breaking after n iterations), and the associated notion of amendable channels (i.e. maps which can be prevented from becoming entanglement-breaking after iterations by interposing proper quantum transformations). Explicit examples were analyzed in the context of qubit and one-mode Guassian channels. For the latter an experimental proposal was also developed in Ref. [6].

In Ref. [7,8] we presented a new decoding procedure to transmit classical information in a quantum channel which, saturating asymptotically the Holevo bound, achieves the optimal rate of the communication line. Differently from previous proposals, it is based on performing a sequence of (projective) YES/NO measurements which in N steps determines which codeword was sent by the sender (N being the number of the codewords). Our analysis shows that as long as N is below the limit imposed by the Holevo bound the error probability can be sent to zero asymptotically in the length of the codewords.

Finally in Ref. [9] we discuss ergodicity in the general case where the fixed point of the open quantum system transformation is not a full-rank (faithful) density matrix. Notably, we show that ergodicity is stable under randomizations, namely that every random mixture of an ergodic channel with a generic channel is still ergodic. In addition, we prove several conditions under which ergodicity can be promoted to the stronger property of mixing. Finally, exploiting a suitable correspondence between quantum channels and generators of quantum dynamical semigroups, we extend our results to the realm of continuous-time quantum evolutions, providing a characterization of ergodic Lindblad generators and showing that they are dense in the set of all possible generators.

References

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