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Fundamental cost of quantum communication protocols

Statistical mechanics and information theory share a common ground, giving rise to an intricate relationship. The most famous example of this connection is Landauer's erasure principle, which gives a bound on dissipated heat required by an irreversible operation. Our goal is to link concepts from quantum thermodynamics and quantum communication to find a fundamental lower bound on the energy required to perform a generic communication protocol.

In particular, we take into account a noisy quantum channel used to send classical information as in [1], [2], which notoriously fulfills the Holevo capacity bound for an optimal encoding and decoding protocol. Starting from the quantum-mechanical setup of Landauer's principle shown in [3] we aim at applying it to a measurement process (as in [4]) which is a crucial source of heat dissipation in such processes.

We then analyze the communication protocol and show that an asymptotically good encoding (i.e. one that reaches the capacity limit) is also optimal in terms of energy requirement. Moreover, we compute the relevant figure of merit, which is the heat dissipated per bit of information sent (ΔQ). We show that in the asymptotic limit this is fundamentally related to the incoherent information of the channel, $\beta\Delta Q \geq \frac{1}{C}\sum_x p(x)S(\rho(x))$, where β is the inverse temperature, C is the channel capacity and $\{x\}_X$ is the alphabet.

The result provides a new physical meaning to the incoherent information, intuitively stating that a noisier channel will also perform worse in terms of required energy and dissipate more. It also gives new insights on how disturbances in states' transmission is correlated with heat generated to decode the message.

The analysis is also quite extensible to other types of channels or to similar protocols.We argue that a natural extension is QKD, where the channel capacity gets replaced by the private capacity (Devetak-Winter bound) and the noise source is the eavesdropper. These kind of considerations could easily lead to a link between energy consumption and correlations erasure, giving an energetical requirement on the security of a private channel.

References:
[1]: Schumacher and Westmoreland. Phys. Rev. A, 56:131–138, Jul 1997.
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Theme

Theme 1. Energy advantage and cost of quantum technology

Primary authors: FIERRI, Claudio (Scuola Normale Superiore); CENTRONE, Federico (ICFO); YEHIA, Raja (ICFO); Dr MIR, Alimuddin (ICFO)

Presenter: FIERRI, Claudio (Scuola Normale Superiore)

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