Quantification of energy consumption of quantum resource distribution ICQE2025

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One of the main tasks of quantum information processing is generating, manipulating, and using quantum resources. Prominent examples of such resources are quantum entanglement and quantum secret key, which are planned to be used in future quantum networks, e.g., for distributed quantum computing and secret communication, respectively. In these networks, quantum resources will be distributed via quantum channels. Due to channels imperfections, this process is expected to involve energy consumption. The consumption takes place during both passing input to the channel and the distillation of imperfect resources taken from the channel's output to its almost perfect form. For this reason, we propose estimating and minimizing this consumption as one of the important tasks on the way to resource aware quantum information processing.

We then establish a quantitative study of energy expenditure in producing quantum resources via quantum channels. We distinguish technological and fundamental energy costs. Technological cost depends on hardware; hence, it is not a fixed quantity. We then focus mostly on the fundamental one. We provide a general definition for the minimal, i.e., unavoidable fundamental energy consumption in creating a maximally resourceful state expressed in units of Jule per rbit (energy invested while generating a unit of resource). We then provide an upper bound on this quantity in case of generated quantum entanglement encoded as polarization on photons, based on three quantum entanglement distillation protocols including original BBPSSW protocol.

We further derive a lower bound on the fundamental energy cost of the standard procedures of entanglement distribution (taking maximally entangled states as input to the channels). Hence, under the contemporary design, we provide a quantitative estimate (a lower bound) of the inevitable energy consumption in future quantum networks.