Single-particle communication through correlated noise

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When a transmission line is used multiple times, the noisy processes occurring in different uses generally exhibit correlations. Here we show that, contrary to classical intuition, these correlations can enhance the amount of information that a single particle can transmit. In particular, a transmission line that outputs white noise at every time step can exhibit correlations that enable noiseless classical communication. In a scenario involving multiple transmission lines, time-correlations can be used to simulate the application of quantum channels in a superposition of alternative causal orders, and even to surpass the communication capacities achievable in such a scenario. *The following is an extended abstract of [1]*: `https://arxiv.org/pdf/2004.06090.pdf`.

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Quantum communication enables new possibilities that were unthinkable in the classical world, notably including the possibility of secure key distribution [2, 3]. A practical hurdle in the implementation of quantum communication, however, is that noise can spoil the transmission of quantum information. To tackle this problem, quantum error correction schemes encode information into multiple quantum particles, using redundancy to mitigate the effects of noise [4–6].

When the same communication channel is used to transmit a stream of particles, the noisy processes experienced by different particles are generally correlated [7–10]. For example, photons transmitted through an optical fibre are subject to random changes in their polarisation [11], and since such changes happen on a finite timescale, photons sent at nearby times experience approximately the same noisy processes.

The presence of correlations is both a threat and an opportunity for communication. On the one hand, it can undermine the effectiveness of standard error correcting schemes, which assume independent errors on the transmitted particles. On the other hand, tailored codes that exploit the correlations among different particles can enhance the transmission of information [7, 9, 12–26].

In this work, we show that, contrary to classical intuition, the correlations between different uses of a communication channel can enhance the amount of information that a *single* particle can carry. Classically, a particle can only enter the communication channel at a definite (possibly random) moment of time, and the correlations between different uses of the channel do not affect the amount of information the particle can carry. In contrast, a quantum particle can be sent through the channel at an indefinite time, as illustrated in Figure 1. Taking advantage of this fact, we show that a communication channel that outputs white noise at every definite time can be converted into a perfect classical channel if the different uses of the channel are suitably correlated.

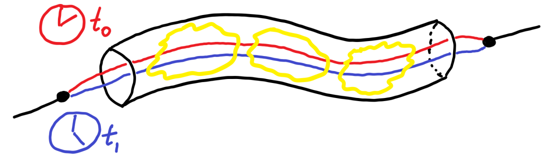

FIG. 1. A single particle is sent through a transmission line in a superposition of two different times t_0 (red) and t_1 (blue). Along the way, the particle experiences errors (yellow regions), which are generally correlated.

Time-correlated channels are also interesting for foundational reasons. Recently, they have been proposed as a way to reproduce the use of quantum channels in a superposition of different causal orders [27, 28]. In particular, they have been used to reproduce the action of the quantum `SWITCH` [29, 30], an operation that combines two quantum channels in a superposition of two alternative orders. In practice, time-correlated channels underlie all the existing experimental setups inspired by the quantum `SWITCH` [31–36].

Here we show that the access to time-correlated channels is an even more powerful resource than the ability to combine ordinary quantum channels in a superposition of alternative orders. We consider two independent, time-correlated channels, with the property that their action at all time steps is completely depolarising. Remarkably, we find that the time-correlations that reproduce the quantum `SWITCH` are not the most favourable for the transmission of classical information: while the quantum `SWITCH` of two completely depolarising channels yields a Holevo information of 0.049 bits [37], a more sophisticated pattern of time-correlations yields a larger Holevo information of 0.31 bits. The gap between these two values further highlights the potential of time-correlations, which are capable to reproduce the benefits of the superposition of causal orders, and even to surpass them.

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