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Decidability of fully quantum nonlocal games with noisy maximally entangled states

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Abstract: This paper considers the decidability of fully quantum nonlocal games with noisy maximally entangled states. Fully quantum nonlocal games are a generalization of nonlocal games, where both questions and answers are quantum and the referee performs a binary POVM measurement to decide whether they win the game after receiving the quantum answers from the players. The quantum value of a fully quantum nonlocal game is the supremum of the probability that they win the game, where the supremum is taken over all the possible entangled states shared between the players and all the valid quantum operations performed by the players. The seminal work MIP$_*$ = RE implies that it is undecidable to approximate the quantum value of a fully quantum nonlocal game. This still holds even if the players are only allowed to share (arbitrarily many copies of) maximally entangled states.

This paper investigates the case that the shared maximally entangled states are noisy. We prove that there is a computable upper bound on the copies of noisy maximally entangled states for the players to win a fully quantum nonlocal game with a probability arbitrarily close to the quantum value. This implies that it is decidable to approximate the quantum values of these games. Hence, the hardness of approximating the quantum value of a fully quantum nonlocal game is not robust against the noise in the shared states. This paper is built on the framework for the decidability of non-interactive simulations of joint distributions and generalizes the analogous result for nonlocal games. We extend the theory of Fourier analysis to the space of super-operators and prove several key results including an invariance principle and a dimension reduction for super-operators. These results are interesting in their own right and are believed to have further applications.

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