Abstract

Quantum entanglement and nonlocal correlations are essential feature of quantum information and computation with no classical analogues. Apart from being central to the fundamentals of quantum mechanics and quantum information, entanglement is also used as an efficient resource for quantum information processing protocols such as dense coding, teleportation, secret sharing, entanglement swapping, and cryptography. The use of entangled resources to achieve efficient and optimal success in quantum information, in comparison to classical resources, is based on nonlocal correlations existing between the particles. The existence of such long-range correlations in quantum systems thus distinguishes the quantum world from its classical counterpart. Although entanglement and nonlocality are well studied in pure two-qubit systems in terms of entanglement of formation (or some physically equivalent quantity) and Bell Inequality, the description and characterization of multiqubit entanglement and nonlocality is much more complex. In fact the entanglement properties of bipartite mixed entangled states itself require a much better physical interpretation. What makes the problem extremely challenging is probably the characteristic trait of complexity. For example, the Bell-type inequalities for three-qubit pure entangled systems itself either fail to distinguish between bipartite and tripartite inequality or fail to identify the presence of nonlocal correlations in a large set of states. The intricacy of the problem increases further considering the real conditions, i.e., by considering interaction between the principal system and environment, leading to decoherence, which adversely impacts the efficiency of quantum systems; in general.

Initially, the description of quantum correlations was mainly associated with entanglement and nonlocality- separable states were thought to be classical systems not useful for quantum information and computation. This perception has been questioned recently with the identification of few separable systems exhibiting quantum correlations and showing potential to be used as resources for quantum information processing. Quantum discord, for example, is a measure of genuine nonlocal correlations and captures the nonlocality in entangled as well as separable bipartite systems. Although quantum discord describes all types of nonlocal correlations in the system, it is difficult to obtain analytical expressions to evaluate discord due to the optimization procedure involved. A simple description that can be obtained analytically to distinguish the quantum and classical boundary would therefore be of great value.

The Thesis readdresses the question of analysing the entanglement and nonlocality in bipartite and multiqubit entangled systems under real scenarios. For this, we establish analytical relations between nonlocality, state parameters, noise parameters and entanglement measures of several entangled classes in two, three and four-qubit systems under real noisy conditions. We further extend our analysis to study the applications of weak measurement and its reversal operations on the nature of correlations existing between the qubits in noisy environment. Interestingly, we find that more nonlocal correlations in the initially prepared state not always guarantee higher efficiency in quantum communication protocols. The analytical results obtained in the Thesis are in complete agreement with the numerical optimization. Moreover, we also propose a class of two-qubit mixed states which is demonstrated to be much more efficient in quantum information processing, than several other two-qubit pure and mixed states. We further emphasize on the usefulness of mixed entangled resources for quantum information and computation in terms of fully entangled fraction, nonlinear entanglement witness and Horodecki's measure. In multiqubit systems, we consider to characterize nonlocal properties of three- and four-qubit Greenberger-Horne-Zeilinger states, three-qubit Slice states, three-qubit W and W_n-type states under real conditions. We believe that our results will be of significant importance as

all the multiqubit states considered for analysing entanglement and nonlocal correlations are experimentally viable.

In addition, we also study the usefulness of quantum correlations in an arbitrary two-qubit state in a biased scenario, i.e., a situation where Alice and Bob perform measurements on their respective qubits with a certain bias. Our results show that quantum theory offers advantages over classical theory for the whole range of biasing parameters. The analysis is further extended using fine-grained uncertainty relations to distinguish between classical and quantum correlations.

For a generic description to characterize nonlocal correlations between qubits, we propose to use statistical correlation coefficients and modify the two-qubit Bell-CHSH and the three-qubit Svetlichny inequality to analyse nonlocality in two and three-qubit entangled systems, respectively. For two-qubit systems, we demonstrate a necessary and sufficient condition for the violation of modified inequality. Further, we describe a simple way to evaluate geometric discord in terms of correlation coefficients and establish a relation between geometric discord and modified Bell-CHSH inequality to understand and interpret nonlocality in terms of correlation coefficients. For three qubit pure Greenberger-Horne-Zeilinger states, unlike the original inequality which fails to detect nonlocality in a large set of states, our modified inequality identifies the presence of nonlocal correlations in all the Greenberger-Horne-Zeilinger states.

In addition, we also study the properties of a special class of non-maximally entangled four-qubit W-type states. Our results show that the class of states are highly useful in quantum information and computation. We generalize our analysis for deterministic transfer of information using N-qubit W-type states as resources. The importance of the proposed class, however, is limited by the realization of experimental set-ups to perform and distinguish multiqubit joint measurements. We, therefore, propose another efficient protocol to use non-maximally entangled W-type states for sharing an optimal bipartite entanglement. Interestingly, our analysis also suggests that four-qubit W-type states can be preferred as resources in comparison to three-qubit W-type states for certain ranges of state parameters. For practical implementation, we further propose a method to experimentally prepare W-type states using standard single and two-qubit measurements.

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