Entanglement Distribution Rates Using Quantum Repeaters Based on Two-Species Trapped Ions

S Muralidharan¹, S Santra¹, C Monroe², L Jiang³, and V S Malinovsky¹

¹US Army Research Laboratory, Adelphi MD, USA
²Department of Physics, University of Maryland, College Park MD, USA
³Department of Applied Physics, Yale University, New Haven CT, USA
Contact Email: vladimir.s.malinovsky.civ@mail.mil

The distribution of entanglement over long distances is crucial for future applications such as quantum key distribution and quantum networks. Quantum communication and key distribution with single photons offers unconditional security since any interception can be detected. The attenuation of optical fiber and the operation errors make quantum communication across transcontinental distances very challenging. Quantum repeaters provide an interesting approach to overcome these difficulties by breaking the total communication distance into shorter channels by intermediate nodes, where the problem of photon loss is detected and corrected. Depending on the methods used to overcome loss and operation errors, quantum repeaters have been classified into three generations. There are several promising platforms for implementing quantum repeaters such as trapped ions, NV centers in diamond and superconducting qubits. In this work, we present comprehensive analysis of entanglement distribution rates using repeaters based on two-species trapped ions. We consider two species trapped ions as building blocks for the construction of large scale quantum repeaters across transcontinental distances. The key requirement for our schemes is a swap gate between the communication and memory ions. We use this to propose different architectures of quantum repeaters and show the achievable key generation rates. Dependence of key generations on experimental parameters such as gate error rates, operation time and coupling efficiency to fiber will be discussed.

In the second part of this work, we address entanglement swapping, a key element of quantum networks. We propose a novel entanglement swapping protocol to mitigate the effects of finite lifetime of quantum memory. We demonstrate two orders of magnitude increase in long-distance entanglement generation rate using current state-of-art quantum memories. Specifically, our optimized schedule maximizes the rate of generation of distillable entanglement for given network parameters: charging success probability and memory lifetime. In our proposal, swapping occurs within a finite waiting-time window after which the memories are reset to mitigate decoherence. For a quantum network architecture comprised of many nesting levels our results suggest that an adaptive scheme, where the higher nesting levels swap progressively slower relative to lower levels that swap rapidly, can lead to high rates of long-distance entanglement generation.