QuIC lab's advances in quantum communications: Free space QKD, Device independent Random Number Generation and Decoherence control

Our Quantum Information and Computing (QuIC) lab at RRI Bangalore (https://www.rri.res.in/quic/) has achieved significant milestones across quantum communications, establishing foundational technologies for next-generation quantum networks. Our free space quantum key distribution (QKD) program has systematically addressed all ground-based implementation challenges, positioning us to develop satellite QKD payloads. With several critical milestones including the first free space entanglement based QKD through an atmospheric channel in 2021, successful demonstrations of entanglement-based QKD between a stationary source and a moving platform in 2023, we have been directly validating key technologies for satellite-based implementations. Through comprehensive atmospheric simulations across the Indian subcontinent, we identified optimal ground station locations including IAO Hanle for uplink transmission. Our innovative polarization compensation approach eliminates active feedback requirements while maintaining 94% fidelity with singlet states, achieving quantum bit error rates of ~5% and key rates of ~35 Kbps. The development of qkdSim, our comprehensive simulation toolkit, enables accurate modelling of experimental imperfections with excellent agreement between simulation and experimental results.

Decoherence control represents a critical advancement for quantum communications, as environmental interactions fundamentally limit quantum system performance and communication fidelity. We have established a unified framework using time-dependent formalism to manipulate quantum entanglement degradation. Our experimental demonstrations show precise control over Entanglement Sudden Death through local unitary operations and amplitude-damping channels, enabling the ability to hasten, delay, or completely prevent decoherence effects in photonic systems.

Finally, our quantum random number generation advances provide essential cryptographic foundations. Using macrorealist inequality violations through the Leggett-Garg inequality, we have developed semi-device-independent approaches across photonic and superconducting platforms. Our implementations systematically address all relevant loopholes, achieving exceptional violations and generating truly unpredictable bits at practical rates, extending from interferometric setups to current quantum computers.

In this talk, we will cover essential aspects of all these developments, ending with our vision for the future quantum internet through the technology group on multi node entanglement distribution based quantum repeater networks, which we are leading as a part of India's National Quantum Mission.