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Performance Analysis of Satellite-Based Classical and Quantum Communication with Adaptive Optics

Secure long-distance communication has become a fundamental requirement in modern information systems, particularly in satellite-based networks where the exchange of sensitive data across vast distances is often exposed to eavesdropping, signal degradation, and transmission errors. Classical communication systems, though widely deployed, face limitations in ensuring unconditional security due to their susceptibility to interception and computational attacks, while quantum communication systems based on principles such as quantum key distribution (QKD) offer theoretically unbreakable security but are highly vulnerable to photon loss, atmospheric turbulence, and channel noise [1-4]. The problem addressed in this study is the challenge of maintaining high fidelity in transmitted bits when signals traverse different satellite orbits—Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Earth Orbit (GEO)—where distance directly impacts photon loss, error rates, and the final usable key size. To mitigate these issues, we propose a comparative simulation model that evaluates the performance of both classical and quantum communication under varying satellite altitudes, incorporating photon loss, repeater effectiveness, and error correction efficiencies, with and without the inclusion of adaptive optics (AO). The methodology involves simulating the transmission of a fixed number of bits while applying altitude-dependent photon loss factors, signal amplification via repeaters, and system-specific error correction mechanisms, followed by the integration of adaptive optics to reduce atmospheric-induced photon scattering [5-7]. Results are visualized using tabular and graphical analyses that highlight the differences in post-correction matching bits across classical and quantum systems under LEO, MEO, and GEO conditions. The findings indicate that while both systems suffer severe degradation at GEO levels, adaptive optics significantly enhances performance in LEO and MEO by reducing effective photon loss, leading to higher matching bit counts after correction. Classical systems tend to retain slightly higher performance due to stronger error correction mechanisms, but quantum systems with AO demonstrate competitive outcomes, proving that physical-layer optimizations can partially compensate for quantum channel vulnerabilities[8][9]. In conclusion, this work demonstrates that integrating adaptive optics into satellite-based communication systems is a promising approach to mitigate photon loss, particularly for quantum systems aiming to scale toward global secure communication. The comparative analysis offers insight into the trade-offs between classical and quantum communication, reinforcing the necessity of hybrid solutions that combine physical channel enhancements with advanced error correction to achieve robust and secure satellite communication in future space-based networks.

Author: BARMAN, Moushumi (Assam Don Bosco University)

Co-author: Dr NANDI, Gypsy (Assam Don Bosco University)

Presenter: BARMAN, Moushumi (Assam Don Bosco University)

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