Dynamic Link-State-Based Hybrid Communication Scheme for Low Earth Orbit Satellite Networks*

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Abstract

In LEO satellite communications, transmission fidelity decreases due to atmospheric turbulence and long distances, with the uplink channel being particularly vulnerable. T his paper proposes a dynamic hybrid communication scheme that dynamically switches between direct transmission and quantum teleportation based on real-time channel estimation. Experimental results show that the proposed method improves average fidelity by 1.23% and throughput by 6.78% compared to single mode.

1 Introduction

Low Earth Orbit (LEO) satellite communication systems are emerging as a key technology for next-generation 6G networks due to low latency and high data efficiency. However, in practical satellite–ground links, atmospheric turbulence and long transmission distances cause signal attenuation and phase instability, degrading transmission fidelity [1]. The uplink channel is particularly vulnerable due to accumulated beam spreading and phase distortion [2]. To address this, this study compares the fidelity of direct transmission and quantum teleportation under varying turbulence and distance. It proposes a dynamic hybrid LEO communication framework that dynamically switches transmission modes using machine learning.

2 Dynamic Link-State-Based Hybrid Communication Scheme

This section explains the operation of the proposed dynamic hybrid LEO satellite communication scheme. Figure 1 illustrates its transmission process. Conventional satellite–ground links consist of an uplink and a downlink. The uplink suffers severe signal attenuation from turbulence near the ground due to beam spreading and angular deviation, while the downlink is relatively stable. Quantum teleportation reduces transmission loss by reconstructing quantum states using entangled resources. Based on real-time channel information such as turbulence intensity and distance, the proposed framework automatically selects direct transmission or teleportation mode that ensures higher fidelity. Using a Random Forest model, transmission modes are dynamically switched to enhance both fidelity and resource efficiency in the uplink.

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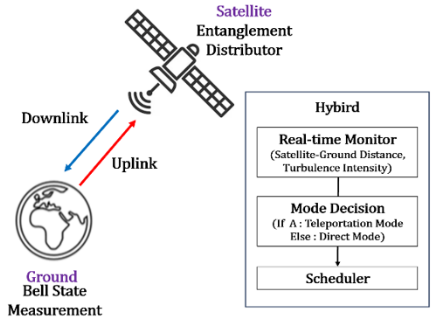

Figure 1: Process of Downlink, Uplink, Teleportation, and Dynamic Link-State-Based Hybrid Transmission Scheme

3 Evaluation results and Conclusion

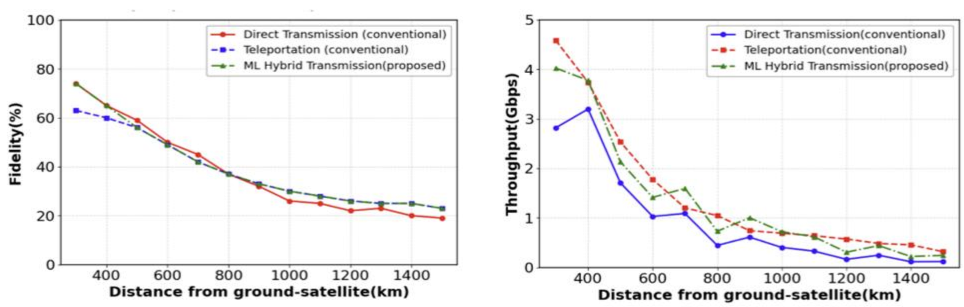

Figure 2: Comparison of Direct, Teleportation, Hybrid transmission fidelity, throughput versus distance under turbulence intensity of 0.1

Figure 2 shows the fidelity and throughput of direct transmission, teleportation, and the proposed method at a turbulence intensity of 0.1 as the transmission distance increases. At 300 km, the fidelities of direct transmission, teleportation, and the proposed method were 74%, 63%, and 74%, respectively, while at 1500 km they were 19%, 23%, and 23%. The proposed method maintains stable fidelity in long-distance and turbulent environments by selecting the optimal transmission mode based on the crossover point of the two methods. The average fidelity of direct transmission and teleportation was 38.23%, whereas the proposed method achieved 39.46%, showing a 1.23% improvement. Throughput was 1.07 Gbps for direct transmission, 1.29 Gbps for teleportation, and 1.26 Gbps for the proposed method, demonstrating stable performance across all distances. Therefore, the proposed scheme effectively maintains transmission quality under varying turbulence intensities and distances.

References

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