
Toward a quantum internet for healthcare: a tiered hybrid network topology

A. Lawande, S. Shere, K. Kamble, S. Salunkhe

Zeal College of Engineering and Research, 122e10413@zealeducation.com,
122e10490@zealeducation.com, 122e10220@zealeducation.com, salunkhe.saurabh@zealeducation.com

Abstract.

Healthcare networks today face a growing threat where encrypted medical records can be intercepted and stored by adversaries to be decrypted once quantum computers become mature i.e. "Q-Day". The "Harvest Now, Decrypt Later" threat makes current cryptographic methods insufficient for ensuring long term data security. To address this, a tiered hybrid Quantum Key Distribution architecture is proposed that allows for different QKD protocols to work together for key exchange between different nodes. Various challenges involved are discussed in this paper.

Keywords. Quantum Key Distribution, Healthcare Security, Hybrid Topology

1. INTRODUCTION

Digitization of health records has made it easier for healthcare providers to share and work with patient information remotely but this has also introduced some vulnerability. The HNDL threat is increasing as encrypted health records that are intercepted today can be stored and decrypted later. Quantum technologies have also been in the forefront for securing medical data [1] Post Quantum Cryptography appears to be more economic and practical than QKD approaches but may become vulnerable in the future. But Quantum Key Distribution introduces a new set of vulnerabilities such as the cost, distance limits, detector weaknesses, and differences in hospital infrastructure making QKD integration into healthcare networks challenging. With classical nodes being agnostic to the QKD protocol it is possible to use these protocols in combinations based on the infrastructure and network traffic.

2. RELATED WORK

Ren et al. [2] proposed combining CV-QKD and DV-QKD within a single network to balance key rate and transmission distance but this increases complexity. Zhong et al. [3] highlighted that scaling TF-QKD to multiple users introduces challenges in phase stabilization, particularly when interferometer paths differ significantly. Other work has

focused on improving scalability. Wang, Xu, and Lo [4] proposed allowing users to independently adjust intensity settings to compensate for channel loss instead of automated synchronicity in common approaches. Reducing centralized dependency, this is useful for star-based topology. Conversely Xu et al. [5] observed that CV-MDI-QKD out-performs only in asymmetric network layouts and not when detectors are equidistantly placed. Sun et al. [6] also observed that temporal-mode mismatch can reduce measurement fidelity at high transmission speeds, which is critical for emergency scenarios. Xu et al. [7] demonstrated quantum and classical signals can coexist over same shared fibre, Wang et al. [8] and Milovancev et al. [9] reported key rates high enough for suitable applications such as 5G fronthaul and healthcare IoT. Liu et al. [10] showed that quantum-aware routing can significantly improve key rates over to simple allocation methods. Ding et al. [11] proposed noise-aware resource allocation, which is particularly relevant for balancing key generation and consumption in dynamic networks as most QKD hardware is classical, prone to photon loss and heat induced errors. Chen et al. [12] demonstrated a metropolitan QKD network using a star topology over existing fiber infrastructure, providing a useful reference for centralized designs, NEC, NICT, and Zenmu Tech [13] in Tokyo implemented secure transmission of medical records using QKD with an All-or-Nothing Transform already in 2019 distributing data across multiple locations. Karinou et al. [14] showed that CV-QKD can integrate with existing WDM infrastructure, which is important for healthcare providers that cannot afford completely replacing existing system.

3. PROPOSED WORK

Each metropolitan city has its own unique network constraints, optimum algorithms and network topologies which can be deployed with different protocols via quantum routers at each node point, keys can be exchanged between these nodes via the communication between key management layers. A central node serves as both a Charlie measurement station for MDI-QKD and a ground station for satellite QKD in each metropolitan region. This dual role implies a partial trust assumption in the central node. The central node can act as a key manager entity, QKD protocol runs on each spoke because standards like ETSI QKD 014, SKIP of Cisco are protocol agnostic. This tiered approach enables a "trickle-down" key distribution model where high-security keys from satellite or TF-QKD backbones can be routed through the central node to resource-constrained nodes. The approach is similar to listed in [15] where the central node has all the expensive equipment, which proposes a network where each user requires only a photonic transmitter chip. As healthcare facilities are government certified this central node should be audited with strict policies by network provider as mentioned in [16]. Another alternative approach would be as mentioned in [17] using multiple satellites from different operators simultaneously with multiple central receiver stations on ground. This would mitigate the central node dependency.

4. RESULTS

We simulated protocols across the three tiers to evaluate the protocols performance and QBER rates to match with the distance using the SeQUeNCe [18], a python library for QKD simulations. BB84 protocol performed well at 40 km distances keeping low error rates (around 0.31%) and delivering key rates in the range of 4.41×10^5 bits per second.

MDI-QKD at 80 km total distance, MDI-QKD maintained a stable performance having a key rate close to 1.18×10^5 bits per second and error rate of 0.20%. TF-QKD has lower key rate of around 3.9×10^4 bits per second with a 90% CI of 2.68×10^4 to 5.73×10^4 bits per second and phase error of 1.0% but enables secure communication over long range up to 400 km as shown in Figure 1.

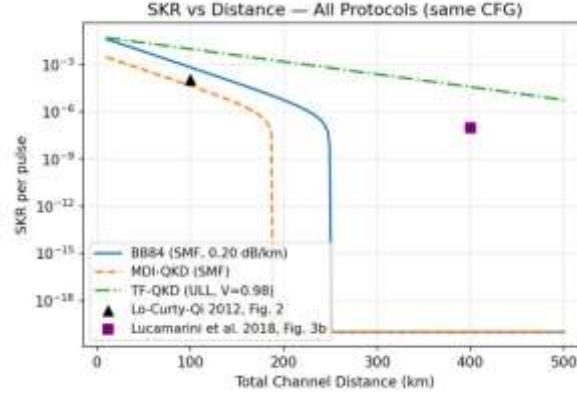


Figure 4.1. SKR per pulse vs distance for all three tiers under identical hardware parameters. Reference points from [19] and [20] shown for comparison.

To account for real-world hardware variation, 200 Monte Carlo trials were run with small random perturbations on detector efficiency, attenuation, and misalignment to produce confidence intervals.

5. REFERENCES

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Biographies



Aadesh Lawande received the bachelor's degree of engineering in artificial intelligence and data science from Savitribai Phule University in 2026, currently pursuing Master's in Quantum Computing from D.Y. Patil Akurdi



Stavan Adesh Shere received the bachelor's degree of engineering in artificial intelligence and data science from Savitribai Phule University in 2026, currently working in Industry as a professional.



Kashyap Kamble received the bachelor's degree of engineering in artificial intelligence and data science from Savitribai Phule University in 2026.



Saurabh Jitendra Salunkhe received the bachelor's degree of engineering in artificial intelligence and data science from Savitribai Phule University in 2026 and is currently working in industry as a professional.