Firstly, in the title ‘The Key to Scalable Quantum Networks’, by networks it means a collection of devices over the internet and **NOT** the networks in a neural network. Meaning this topic is more tuned towards Computer Network s.

Quantum communication promises secure data exchange and enables distributed quantum computing through entanglement. However, scalability faces challenges due to decoherence, noise, operational errors, and photon loss. Quantum repeaters are essential to extend quantum communication distances. Unlike classical repeaters that amplify signals, quantum repeaters create intermediate nodes for entanglement swapping and purification, thus extending communication ranges without loss of quantum coherence.

**Decoherence**: This occurs when quantum states lose their coherence over time, severely affecting communication quality. Decoherence becomes a major issue when scaling over long distances or increasing the number of network nodes.

**Photon Loss**: Quantum information encoded in photons can degrade or be lost as the distance between nodes increases.

**Noisy Intermediate-Scale Quantum (NISQ) Devices**: NISQ devices are operational but face significant noise, and their scalability is constrained by quantum operation errors and noise-induced decoherence.

A model called E-QNet (Entanglement-assisted Quantum Network Protocol Stack) emphasizes the need for a \*\*quantum protocol stack\*\* that handles entanglement distribution, quantum error correction, and high-fidelity qubit transmission to support applications like quantum cryptography and quantum computing.

Layer 1: Physical Layer: This layer handles the transmission of qubits and entangled states via photonic channels. The key challenge here is entanglement generation and minimizing qubit decoherence over distance.

Layer 2: Link Layer: Responsible for reliable entanglement distribution (ED) and entanglement purification (EP). This layer ensures that generated entanglement is of high quality and ready for use by upper layers.

Layer 3: Network Layer: Manages entanglement swapping (ES) to extend the reach of quantum communication over longer distances. Entanglement swapping occurs at quantum routers and repeaters to create long-distance entanglement links between nodes.

Layer 4: Transport Layer: Manages quantum teleportation and ensures reliable qubit transmission using pre-established entanglement links.

Layer 5: Application Layer: Supports high-level quantum applications such as Quantum Key Distribution (QKD) quantum computing algorithms, and other quantum cryptographic protocols.

Quantum Key Distribution (QKD): The paper emphasizes QKD as a critical application of quantum networks. QKD uses entangled qubits to generate a shared, secure key between two parties, and this process benefits greatly from the scalability of quantum networks.