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Towards a Fully Connected Many-User Entanglement Distribution Quantum Network Within Deployed Telecommunications Fibre-Optic Infrastructure

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Abstract: We present developments in entanglement distribution quantum networks towards a fully connected, scalable, many-user network, which is not limited to simple quantum key distribution protocols.
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Quantum networks have now been shown to allow efficient quantum communication between more than just two parties [1,2]. The technology has demonstrated use cases beyond standard point-to-point quantum key distribution (QKD), such as quantum teleportation [3], coexistence scheme of quantum and classical channels in a single fibre [4], and other quantum protocols [5]. Building on prior work [6], we present development of a many-user fully connected entanglement distribution quantum network architecture, that maintains the ability to perform protocols beyond just QKD, and our work towards true scalability within a metropolitan area.

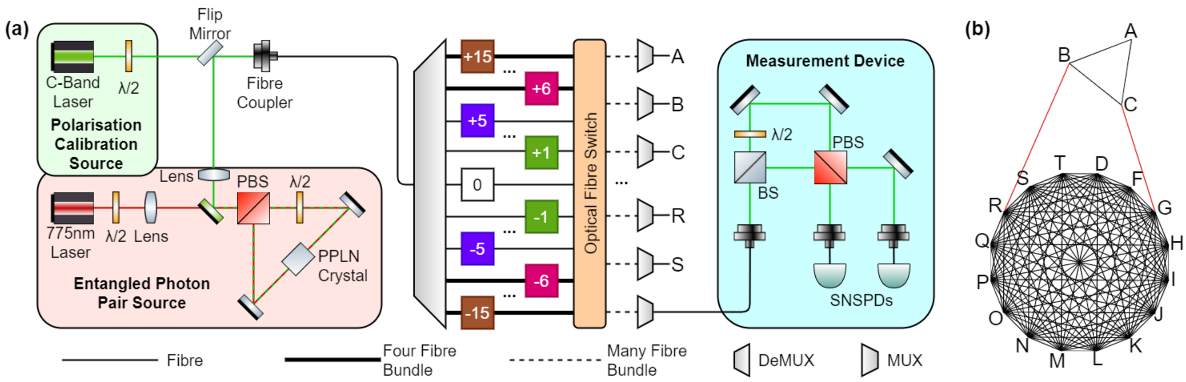

Fig. 1. The network architecture of our system. **(a)** shows the setup of the network source, the distribution system, and the resource efficient user measurement device. Here $\lambda/2$ is a Half-Wave Plate, PBS is a Polarisation Beam Splitter, BS is a 50:50 Beam Splitter, and SNSPD is a Superconducting Nanowire Single-Photon Detector. The DeMUX and MUX are demultiplexer and multiplexer respectively. Boxes on fibre links show an FPC for the specified wavelength channel. **(b)** shows an example of users connectivity in the network. Black lines are fixed links between users and Red lines are active links to change the connectivity between the two groups of users. Users A, B, and C are long distance users who are external to the QLAN.

Our work utilises a broadband bi-partite polarisation entanglement source, which is multiplexed into 30 separate 100 GHz ITU-T channels. For convenience, we denote ITU-T channel 19 (191.9 THz) to channel 49 (194.9 THz) as ch_{-15} to ch_{+15} respectively, where photons in ch_{-i} are entangled with ch_{+i} (i to be integer ≥ 1) due to type-0 spontaneous parametric down-conversion (SPDC) of pump laser to be 775.06 nm. ch_0 is operating at 1550.12 nm and is not entangled with any other channel, so can be used to measure the SPDC rate. From these channels, ch_{-5} to ch_{+5} use the full signal without any beam splitting, and the remaining 20 channels are divided with four-way beam splitters, each into 4 sub-channels. This allows each wavelength pair to create a maximum of 16 unique communication links. A fully connected quantum local area network (QLAN) of 16 users is possible using only 20 wavelength channels, shown in Figure 1(b). A cluster of long distance users can then be added using 6 full power channels to form a 3-user quantum network. The remaining 4 wavelength channels are used to actively interconnect the QLAN with the external users, for the required connectivity for various scenarios and use cases, to form a 19-user quantum metropolitan area network.

The birefringence of optical fibre used in telecommunications infrastructure causes quantum bit (qubit) state rotations due to temperature fluctuation and fibre curvature changes. This leads to a mismatched basis measurement of the polarisation-based qubits between parties. By embedding fibre polarisation controllers (FPCs) into the distribution system, we can neutralise the full fibre length, from source to user, with one FPC per wavelength channel per user. As shown in Figure 1 (a), this is done by connecting a DeMUX to the source output, and routing the channels through FPCs and then into an Optical Fibre Switch (OFS). The OFS then connects the channels to the user MUXs, which then sends all quantum channels to a user through a single fibre connection. The connections are neutralised with a wavelength-tunable polarised C-Band laser that is used to recover two definitions of polarisation at each user. In previous demonstrations [2], more than one wavelength travelled through the same FPC which posed great challenge to fibre neutralisation. The upgrade in this work allows an increased link stability for longer system operational time, of up to three days for the QLAN, without sacrificing operational time from frequent polarisation compensation. With this simple distribution and neutralisation system in place, and the efficient resource design of the measurement device, the full quantum network operates towards increased number of supporting users, more connectivity and higher scalability.

Our system can perform efficient long-distance communication of up to 50 km, with a maximum link Secret Key Rate (SKR) of 5.78 ± 0.21 bps stable over 10 hours. Here, two simultaneous communication links were configured between a distant user and two parties within the QLAN. It has been shown how the SKR in such a system can be optimised through the use of active components, while maintaining a fully connected network [7]. Automation is an important step within a fully connected quantum network, and will allow the connectivity of a system to be adapted for the required protocol. To develop a QLAN for use inside current communication hubs, such as data centres, development of coexistence of quantum and classical channels within standard telecommunication fibre is required. This has been shown for point-to-point quantum communication links [4] and initial data shows promise for connecting users together via an entanglement distribution quantum network with minimal detriment to the quantum signal.

In summary, our system allows for a large-scale, multi-user, entanglement distribution quantum network with dense connectivity graphs to support various quantum protocols beyond simple QKD.

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