Software-defined subcarrier wave quantum networking operated by OpenFlow protocol

V.I. Egorov, V.V. Chistyakov, O.L. Sadov, A.B. Vasiliev, P.V. Fedchenkov, V.A. Grudinin, O.I Lazo, A.E. Shevel, N.V. Buldakov, S.M. Kynev, A.V. Gleim, S.E. Khoruzhnikov, S.A. Kozlov

ITMO University, Department for Photonics and Optical Information Technology, 199034 Kadetskaya Line 3b, Saint Petersburg, Russia

During the last decade heroic effort has been put into shifting from experimental point-to-point quantum communication (QC) links to multiuser quantum networks functioning in real life environment. As a result, quantum networks were successfully launched over the world, and new types of QC devices, promising from networking perspective, were developed. Among them stand subcarrier wave (SCW) QC systems [1,2], most valuable feature of which is exceptionally efficient use of the quantum channel bandwidth and capability of signal multiplexing by adding independent sets of quantum subcarriers to the same carrier wave [2]. It makes SCW QC systems perfect candidates as backbone of multiuser quantum networks.

Rapid development of quantum networking has raised a question of efficient network and key management. It was recently proposed [3] that adopting newly developed methods of software defined networking (SDN) can be beneficial for QC in terms of connecting different types of QC systems and other network devices in a unified infrastructure. The SDN paradigm separates data transfer from management, leaving the latter to centralized software control plane. At the same time, QC is promising for protecting SDN control plane data. For instance, recently QC was used for securing network function virtualization in the SDN network [4].

In this work we discuss how SDN paradigm can be applied to dynamically operating QC systems and networks on a practical example of SCW QC. Firstly, we show how SCW QC components on different levels can be operated based on network data, increasing the practicality of QC setups. For example, it is known that QC protocol parameters, e.g. mean photon number, need to be optimized depending on external factors such as channel loss in order to achieve a compromise between unconditional security and higher key rate. Normally these hardware parameters are set during system installation. On the other hand, an SDN controller may monitor the link losses in real time and send signals to a programmable attenuator for fine tuning of optical power in the channel to reach optimal secure key rate. Another example is possibility of external phase modulator control in order to add or remove SCW quantum channels on different pairs of sidebands in accordance with current network policies without stopping the system.

We also apply the SDN paradigm to a quantum network as a whole, using OpenFlow protocol for orchestrating routing based on optical links parameters. Since a centralized SDN controller has all the information on current link status, it can be used for network path selection in a distributed network (instead of stopping a problematic QKD session) based on conditions defined by the user. These conditions may include eavesdropping (e.g. QBER > 11%), fiber channel damage (no connection), high channel losses or a signal from a compromised node. In all these cases, SDN controller will automatically perform network switching using backup optical channels. SDN network control may also be used to perform automatic calculation of optimal network paths based on real-time monitoring of link parameters. In a large-scale network the difference in total losses for various routes between two nodes can be very substantial, leading to otherwise non-optimal use of bandwidth and lower key rates.

A principal scheme of the developed SDN-operated QC node is shown in Fig. 1. The functions of different network levels are the following. Quantum level composed of SCW QC system is responsible only for quantum information exchange and optical synchronization of Alice and Bob modules. Network management level, represented by SDN controller, operates the QC devices and components, controls optical switching, monitors link condition, defines optimal signal paths and controls data encoding process. Transport level (SDN switch) performs physical network routing and data encoding. It is connected to a server responsible for data and key storage and processing. Finally, the application level provides end-user interface.

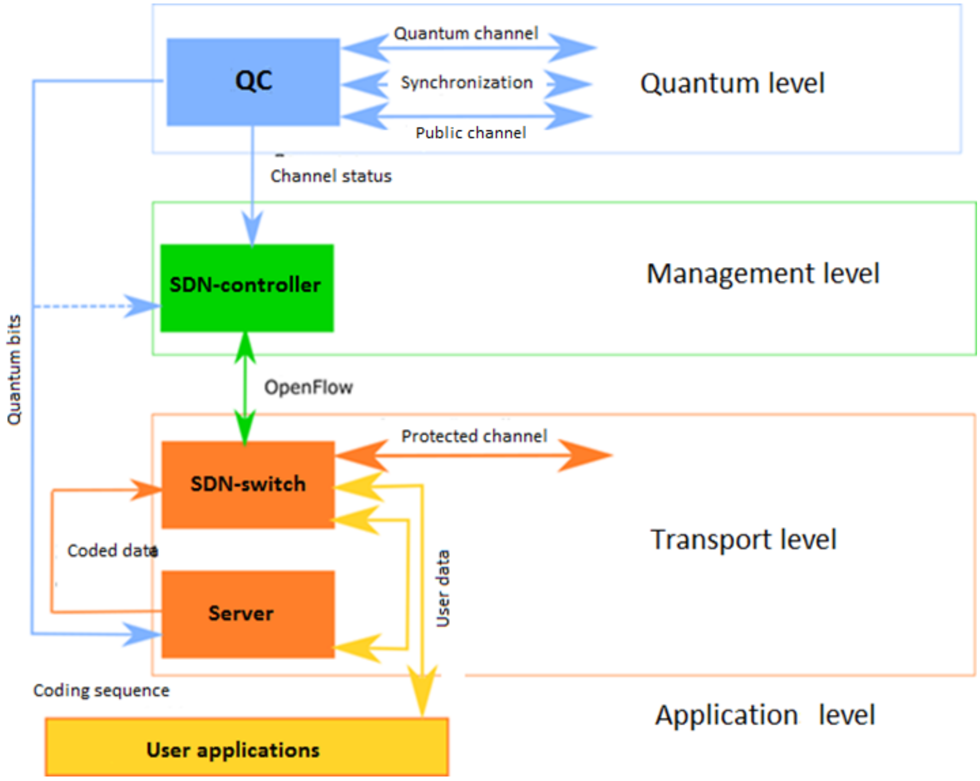

Fig. 1. Principal scheme of OpenFlow-managed QC network node

In order to demonstrate the advantages of the proposed approach, we performed experimental demonstration of an SDN-operated SCW QC testbed. It was shown how an SDN controlled quantum network dynamically responds to a change in link status. When the QC link is unavailable or compromised, the server uses previously stored quantum keys or switches to classic encoding algorithm. The experiments were performed in a three node network composed of high-speed SCW QC systems described in [1] functioning in metropolitan telecommunication infrastructure. The software SDN controllers and hardware SDN switches were communicating using OpenFlow v.1.3 protocol.

The obtained results are important for effective management of future distributed multiuser quantum networks which should be flexible, dynamically adjustable and require no user interference during their normal course of operation.

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