Sub-200 ps Quantum Network Node Synchronization over a 128 km Link White Rabbit Architecture

W. McKenzie[1], Y.S. Li-Baboud[2], M. Morris[1], G. Baumgartner[1], A. Rahmouni[2], P. Kuo[2], O. Slattery[2], B. Crabill[3], M. Merzouki[2], A. Battou[2], T. Gerrits[2]

[1]*Laboratory for Telecommunication Sciences, 8080 Greenmead Drive, College Park, MD, 20740, USA*
[2]*National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, MD 20899, USA*
[3]*Mid-Atlantic Crossroads, 5825 University Research Ct, Riverdale, MD 20737, USA*
Author e-mail address: wmckenzie@ltsnet.net

Abstract: We show sub-200 ps synchronization between quantum networks nodes that are separated by two 64 km deployed fiber links, providing a 128 km link architecture. The architecture employs one grandmaster and two boundary White Rabbit system clocks and shows promise for metropolitan-scale quantum network node synchronization.

1. Introduction

High precision synchronization is essential for any quantum network architecture and quantum metrology. As single photon coherence times vary from several nanoseconds to picoseconds, depending on the physical implementation of the qubit system, high-precision synchronization over long distances in deployed fibers is required. In the extreme case when using spontaneous parametric down conversion (SPDC) as a resource for entanglement distribution and swapping, picosecond synchronization will be required [1]. Compared to classical networks, these synchronization requirements are orders of magnitudes more stringent. As a promising approach, White Rabbit Switches[1] (WRSs), based on the IEEE High-Accuracy Precision Time Protocol (HA-PTP), have been employed in quantum network applications [1, 2]. Here, we use a two-level WRS architecture with one grandmaster (GM) and two boundary clocks (BCs) and show sub-200 ps synchronization between the grandmaster and the final BC, which are separated by 128 km.

2. Experiment

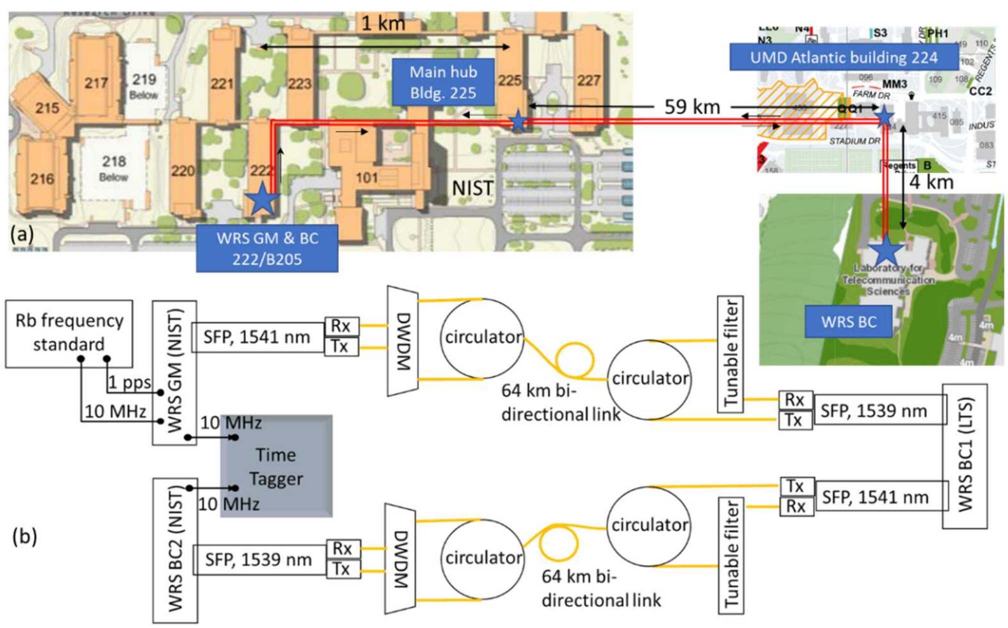

Figure 1. Schematic of the experimental setup. (a) Not-to-scale representation of the deployed optical fiber: A 1 km link within NIST connects the lab to the NIST quantum network hub. A 59 km link connects the NIST campus to the University of Maryland campus, where a further 4 km connection is made to LTS. (b) Schematic of long-distance WRS topology. A WRS serves as a GM disciplined by a Rb frequency standard. The GM distributes HA-PTP to a WRS boundary clock at LTS through a series of optical components to allow for bi-directional signal transport in a single fiber to minimize path delay asymmetry. The WRS BC1 at LTS distributes the HA-PTP back to NIST to a second WRS acting as the second BC (BC2). The arrival of both 10 MHz output rising edges from the GM and BC2 are recorded using a low-jitter time tagger. SFP: Small form-factor pluggable (module); Rx: Receive; Tx: Transmit; NIST: National Institute of Standards and Technology; LTS: Laboratory for Telecommunication Sciences; UMD: University of Maryland

Fig. 1 shows our experimental setup. A 64 km link is established between the grandmaster WRS and the first boundary clock WRS. The first boundary clock WRS redistributes the HA-PTP to a second boundary clock, which is at the same location as the grandmaster. This architecture allows the time delay between the 10 MHz grandmaster clock and second boundary clock to be measured using a low-jitter time tagger [1]. Fig. 1b shows a schematic of the WRS topology. Bi-directional HA-PTP over metropolitan area distances enables more economic use of deployed fibers and can reduce path delay asymmetry and variability. The circulators in the setup enabled the bi-directional operation. However, due to reflections from fiber connectors within the bi-directional path, we had to employ a series of dense wavelength division multiplexing (DWDM) filters and tunable filters to filter out reflected light of the incorrect wavelength from the transmission path.

3. Results

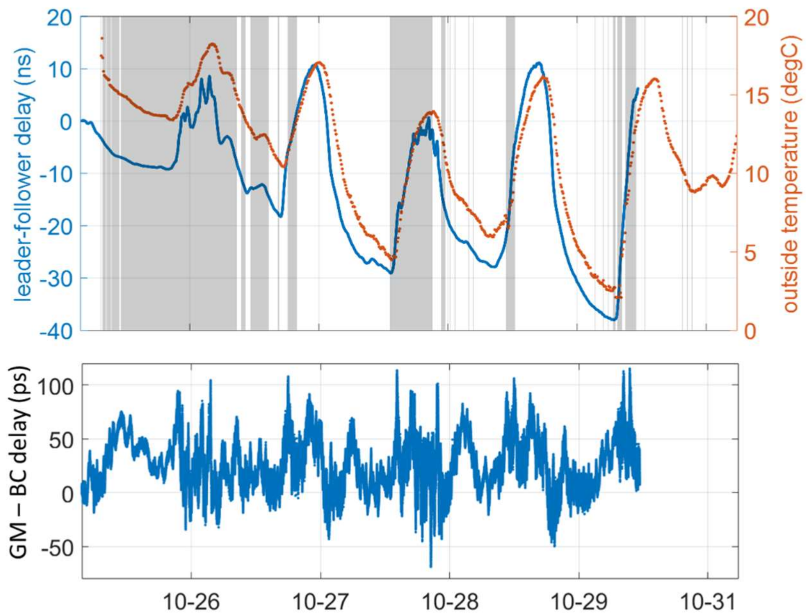

Figure 2. Experimental Results. (a) Leader-follower path delay (blue line) vs. time (date in 2022) between the first boundary clock at LTS and the second boundary clock at NIST. The outside ambient temperature (red line) is also shown. The grey shaded areas represent some degree of cloud cover, mist or fog in the region of deployed fiber. White areas represent clear skies. (b) Total grand master to second boundary clock delay vs. time.

Fig. 2(a) shows the leader-follower path delay between the first and second boundary clock (blue line) and the ambient outside temperature (orange line). The leader-follower path delay appears to correlate with the ambient outside temperature and its value changes by about 50 ns peak-to-peak, while the ambient outside temperature varies by about 15° C. The grey shaded areas represent some degree of cloud cover, mist or fog in the region of deployed fiber, whereas the white areas represent clear skies. Initial analysis suggests that the deployed fiber is partially deployed in the air, *e.g.* between power poles. Fig. 2(b) shows the total grandmaster to second boundary clock delay vs. time, *i.e.* representing the synchronization error over the architecture's total link length of 128 km. The peak-to-peak variation is less than 200 ps.

Our results show promise for metropolitan-scale quantum network node synchronization. Quantum communication protocols requiring single-photon interference with nanosecond photon coherence times should be achievable. We are also working towards metropolitan-scale synchronization based on HA-PTP to allow for protocols employing SPDC photons.

4. References

[1] T. Gerrits, et al. "White Rabbit-assisted quantum network node synchronization with quantum channel coexistence," in Conference on Lasers and Electro-Optics, Technical Digest Series, paper FM1C.2.
[2] M. Alshowkan et al., "Reconfigurable Quantum Local Area Network Over Deployed Fiber", PRX Quantum 2, 040304 (2021)

[1]Certain commercial equipment, instruments or materials are identified in this report to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment are necessarily the best available for the purpose.