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RFC9583 Clock Sync is not a valid Quantum-Internet Application

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Abstract

This internet draft is a critique of RFC 9583, "Application Scenarios for the Quantum Internet". Section 3.2 of that document

presents network clock synchronization as application for quantum internet. The present internet draft argues why it is not.

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1. Introduction

Quantum communication is attracting major investments worldwide. In Europe alone, hundreds of millions of euros are being invested in quantum communication infrastructure, including EuroQCI with a focus on quantum key distribution (QKD), and satellite-based quantum communication. Many of those investments are made with a long-term vision towards a "full" quantum internet. [RFC9583] describes a possible quantum-internet development in six stages, as well as applications and application scenarios.

We studied the QIRG document [RFC9583] in order to validate quantum-internet investments of our own. We found that most applications are less than convincing. Many of the applications could easily be implemented with much cheaper existing technologies. The viability controversies of QKD are well known [Aquina]. Other application scenarios are still at low technology readiness level, like distributed quantum computing.

One application stood out to us, namely network clock synchronization. This application is easily explainable. Moreover, it would provide a potential improvement of a high-value classic application. In order to better understand the quantum-internet application, we involved mathematicians, electrical engineers and physicists of our own organisation, and we consulted with external specialists on clock synchronization and quantum technologies, including some of the original authors. Despite these efforts, we have been unable to refute the null hypothesis, namely that quantum clock synchronization is not a valid application of quantum internet.

This internet draft introduces quantum clock synchronization, and it provides four arguments for the "not-valid" conclusion.

NOTE:

The term "synchronisation" has multiple meanings in scientific literature.

Meaning 1: ("clock synchronization"): adjustment of a clock or watch to show the same time as another.

Meaning 2 ("synthonization"): the process of setting two or more oscillators to the same frequency.

This internet draft is only about the first meaning, as QIRG via [RFC9583] addresses only that meaning. Examples of the second meaning are methods that use entangled photon pairs from physical processes (e.g. spontaneous parametric down conversion), or that use quantum interference of photons (Hong寠徹u寠溺andel effect). The second meaning is out of scope of this internet draft.

2. Quantum Clock Synchronization

[RFC9583], and references therein refer to [Jozsa2000] for "quantum clock synchronisation". [Jozsa2000] introduces three methods for synchronizing a pair of spatially separated clocks, Alice and Bob, which are at rest in a common inertial frame.

1. Einstein Synchronization. This involves an operational line-of-sight exchange of light pulses between two Alice and Bob. This method is based on the presumption that the speed of light, and hence optical distance, is the same from Alice to Bob as vice versa.

2. Eddington’s Slow Clock Transport. In this scheme, Alice and Bob are first synchronized locally, and then they are transported adiabatically (infinitesimally slowly) to their final separate locations.

3. Quantum Clock Synchronization. This third method is quantum-entanglement based, in which Alice and Bob possess shared prior entanglement.

Introduced as three different methods, the third would not rely on either of the other two. In the third method, no actual clocks exist initially but rather only "entangled clocks" in a global state which does not evolve in time. The synchronized clocks are then extracted via measurements and classical communications performed by Alice and Bob, using the Ramsey method. More details are provided by [Jozsa2000], as well as a critique by [Burt] on circular reasoning by [Jozsa2000].

3. Matter-based entanglement requires slow clock transport

[Jozsa2000] assumes shared prior entanglement. The entanglement may be matter-based, e.g. entanglement between pairs of atoms, ions or electrons. That entanglement can only be achieved if those have been close together in the past. As argued by [Burt], there the phase information must be transported quantum mechanically and in such a way that it avoids "classical" perturbations. That means slow clock transport, which would make it a complicated variation of Eddington’s Slow Clock Transport.

Hence, we should exclude matter-based entanglement, and presume the alternative. That is, entanglement between pairs of photons, the units of electromagnetic radiation.

4. Photon-based entanglement does not carry time information

[Jozsa2000] introduces their method as different from Einstein Synchronization. That is, it does not rely on a bidirectional channel with exactly equal delays in both directions. Figure 1 sketches the creation of shared prior entanglement between Alice and Bob. The quantum channel is unidirectional: photons (photonic qubits) travel from Alice to Bob. Those qubits are entangled with qubits that stay with Alice. Alice and Bob have clocks that need to be synchronized. Each of them has a clock output where the clock information is consumed locally. Classical communication (not shown) is used for asynchronous bidirectional exchange of information for the quantum clock synchronization protocol.

```
   a)       +-------+          +-------+
            |       |          |       |
            | Alice | -------> |  Bob  |
            |       |          |       |
            +-------+          +-------+
                |                  |
                V                  V

               Out                Out

   b)       +-------+          +-------+
            |       |          |       |
            | Alice | ---.T--> |  Burt |
            |       |          |       |
            +-------+          +-------+
                |                  |
                V                  V

               Out                Out
```

Figure 1 Effect of delay .T on clock synchronization.
(Showing only the quantum channel: from Alice to Bob & Burt)

The problem with this approach is that light (photons) do not carry time information. If a classical pulse of light is sent from Alice to Bob, and a similar classical pulse of light is sent from Alice to Burt with a delay .T, then Burt will measure the same as Bob, just .T later. This is true, independent of the number of photons in the pulse, or whether the pulse is a single photonic qubit.

We conclude that if Alice synchronizes this way with both Bob and Burt, that Burt’s clock will be lagging .T behind Bob’s clock.

5. No known method can create the required initial conditions without already synchronized clocks

For the algorithm by [Jozsa2000] to work, a shared measurement basis is required between the two quantum systems. However, no practical method is known to the authors which can create this without the use of already synchronized clocks. The same argument was made by [Burt], who argues that the initial paper boils down to circular reasoning.

The only proposed option is to connect the local measurement bases to e.g. absolute orientation in the universe. However, no methods are known to achieve this, and it is suspected by the authors that the concept goes against the rule that absolute quantum phase is irrelevant.

6. Current synchronization solutions suffice

Our final question was why we don’t see more work on quantum clock synchronization by e.g. metrology institutes. We suspect that the reason is economical, and that current clock synchronization solutions based on the first method suffice.

7. Security Considerations

Not applicable. The (in)validity of quantum clock synchronization has no security considerations.

8. IANA Considerations

Not applicable. The (in)validity of quantum clock synchronization has no IANA considerations.

9. Conclusions

We conclude that [RFC9583]-type quantum clock synchronization is not a valid quantum-internet application. We have provided four arguments for this.

- o Matter-based entanglement requires slow clock transport.

- o Photon-based entanglement does not carry time information.

- o No known method can create the required initial conditions without already synchronized clocks.

- o Current synchronization solutions suffice.

These are relevant insights to those who use [RFC9583] as basis for investments in quantum internet.

10. Informative References

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11. Acknowledgments

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Appendix A. Discussion of other references

In the appendix, we briefly discuss other references on quantum clock synchronization. They don’t change the conclusions of this internet draft.

A.1. [Ilo-Okeke]

[Ilo-Okeke] uses entanglement purification, a.k.a. entanglement distillation, to improve the quality of the entanglement. It is based on the same assumptions as [Jozsa2000].

A.2. [Komar]

[Komar] is cited by [RFC9583]. It presumes a perfect GHZ-state as a starting point, similar to [Jozsa2000], which can only be achieved in the presence of already synchronised clocks.

A.3. [Guo]

[Guo] is cited by [RFC9583]. It references [Komar] for clock synchronisation.

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