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Addendum: Protocol for Counterfactually Transporting an Unknown Qubit

Hatim Salih *

Independent Researcher, York, UK

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An addendum on

Protocol for Counterfactually Transporting an Unknown Qubit
by Salih, H. (2016). Front. Phys. 3:94. doi: 10.3389/fphy.2015.00094

We give a simpler, more precise formulation for Equations (1–3) in Salih [1], and consequently for transport fidelity, Equation (15). This does not affect the validity of the protocol nor the scientific conclusions of the paper. The fidelity of counterfactual transport for finite inner and outer cycles is re-evaluated and plotted in **Figure 1** below.

First, the revised Equations (1–3) from Salih [1],

$$\begin{aligned}&(\alpha\,|\text{pass}\rangle + \beta\,|\text{block}\rangle) \otimes |10\rangle \rightarrow \\ &\alpha\,|\text{pass}\rangle \otimes (\cos n\theta\,|10\rangle + \sin n\theta\,|01\rangle) + \\ &\beta\,|\text{block}\rangle \otimes \cos^{n-1}\theta(\cos\theta\,|10\rangle + \sin\theta\,|01\rangle).\end{aligned} \tag{1}$$

$$\begin{aligned}&(\alpha\,|\text{pass}\rangle + \beta\,|\text{block}\rangle) \otimes |010\rangle \rightarrow \\ &\alpha\,|\text{pass}\rangle \otimes (\cos n\theta_N\,|010\rangle + \sin n\theta_N\,|001\rangle) + \\ &\beta\,|\text{block}\rangle \otimes \cos^{n-1}\theta_N(\cos\theta_N\,|010\rangle + \sin\theta_N\,|001\rangle).\end{aligned} \tag{2}$$

$$\begin{aligned}&(\alpha\,|\text{pass}\rangle + \beta\,|\text{block}\rangle) \otimes |100\rangle \rightarrow \\ &\alpha\,|\text{pass}\rangle \otimes \cos^{m-1}\theta_M(\cos\theta_M\,|100\rangle + \sin\theta_M\,|010\rangle) + \\ &\beta\,|\text{block}\rangle \otimes (\cos m\theta_M\,|100\rangle + \sin m\theta_M\,|010\rangle).\end{aligned} \tag{3}$$

Second, the revised Equation (15) from Salih [1] for the approximate fidelity of counterfactual transport, which gets more precise the larger the number of inner cycles, N, gets,

$$\textit{Fidelity} = \left(\cos^M\theta_M + \eta[M,N]\right)^2 \left(\frac{|\alpha|^2}{2}\cos^M\theta_M + \frac{|\beta|^2}{2}\eta[M,N]\right)^2 \tag{4}$$

Note that while a smaller number of outer cycles, M, does not lead to output errors in our counterfactual CNOT gate (the key step in our protocol) for either the case of Bob blocking

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Lorenzo Pavesi,
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****Correspondence:***
Hatim Salih
salih.hatim@gmail.com

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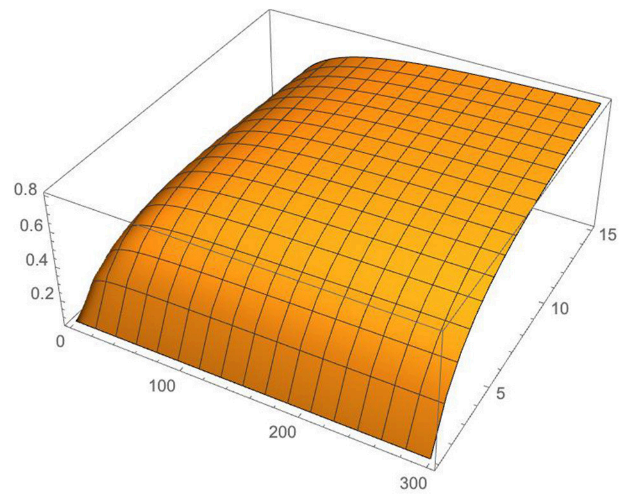

FIGURE 1 | Ideal case fidelity of counterfactual transport. Fidelity is plotted against the number of outer and inner cycles, M and N, for M up to 15 and N up to 300, with $\alpha = \beta = \frac{1}{\sqrt{2}}$. For $M = 15$ and $N = 300$ fidelity is already above 80%. The fidelity of our protocol for counterfactual transport approaches unity for $N \gg M \gg 1$. Implementation imperfections are ignored.

the channel or the case of Bob not blocking the channel, it does lead to reduced fidelity for the case of Bob effecting a superposition of blocking and not blocking the channel. The reason is that for the component of the superposition where Bob does not block, the probability amplitude of Alice's photon is multiplied by a factor of $\cos\theta_M$ after each outer cycle. This can be ignored, however, for large M. Given ideal implementation, the fidelity of our protocol for counterfactual transport approaches unity for $N \gg M \gg 1$, where N and M are the number of inner and outer cycles respectively.

We draw the reader's attention to the fact that the posting of our protocol on the arXiv in 2014 [2] has triggered a number of related papers including, Guo et al. [3], Li et al. [4], Vaidman [5], and Shenoy-Hejamadi and Srikanth [6]. We plan a separate reply to Vaidman's Comment [5].

We finally cite Hosten et al. [7], who first introduced the chained quantum Zeno effect in the context of counterfactual computation, a second time.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and approved it for publication.

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Conflict of Interest Statement: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.