Swapping Intra-photon entanglement to Inter-photon entanglement using linear optical devices

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We propose a curious protocol for swapping the intra-photon entanglement between path and polarization degrees of freedom of a single photon to inter-photon entanglement between two spatially separated photons which have never interacted. This is accomplished by using an experimental setup consisting of three suitable Mach-Zehnder interferometers along with number of beam splitters, polarization rotators and detectors. Using the same setup, we have also demonstrated an interesting quantum state transfer protocol, symmetric between Alice and Bob. Importantly, the Bell-basis discrimination is not required in both the swapping and state transfer protocols. Our proposal can be implemented using linear optical devices.

I. INTRODUCTION

Quantum physics emerges as a surprising yet natural outgrowth of the revolutionary discoveries of physics during the first decade of twentieth century and has resulted in an extraordinary revision of our understanding of the microscopic world. Some quantum features can be exploited for information processing tasks. In recent decades a flurry of works have been performed, which includes storage and distribution of information in between non interacting system (for reviews, see [1]). Quantum entanglement is a fundamental resource for performing many information processing tasks including secret key distribution [2] and dense coding [3]. In 1993, Bennett and colleagues [4] put forwarded a path breaking protocol for transporting an unknown quantum state from one location to a spatially separated one - a protocol now widely known as quantum teleportation. A shared entangled states between the two parties and a classical communication channel are required to perform the quantum teleportation task. Right after this proposal, Bouwmeester et al. [5] and Boschi et al. [6] experimentally implemented the teleportation protocol using photonic entangled state. Later, various other systems, such as atoms [7,8], ions [9], electrons [11] and superconducting circuits [12,13] have been used for experimentally demonstrating teleportation and interesting extensions were subsequently proposed, specially those regarding the teleportation of more than one qubit [14].

By exploiting the notion of quantum teleportation a fascinating consequence emerges known as entanglement swapping [16,17]. In a swapping protocol, the entanglement can be generated between two photons which have never interacted. If photon A entangled with photon B and C entangled with photon D, then the entanglement can be created between A and D, although they never interacted in the past. However, the photons B and C need to be interacted with each other. The swapping of entanglement has been extensively studied both theoretically [16,17] and experimentally [18-21]. It is worthwhile to mention here that both the teleportation and entanglement swapping protocols require the Bell basis discrimination which is practically a difficult task to achieve using linear optical instruments. A number of experiment have recently been conducted to perform the Bell basis analysis using linear optical devices [22,28].

The primary aim of the present paper is to demonstrate an interesting entanglement swapping protocol so that the intra-photon entanglement between the two degrees of freedoms of single photon is swapped to the intra-photon entanglement between two spatially separated photons. Note that, the inter-photon entanglement is relatively more fragile than intra-photon one because the former is more prone to decoherence. In an interesting work [29], the swapping of this kind was proposed. In this work, we use a different and elegant setup than that is used in [29] but similar to [30] to propose our entanglement swapping protocol. The same setup can be used to perform quantum state transfer which is technically different from the usual teleportation protocol. Both of our swapping and state transfer protocols do not require Bell-basis discrimination. Although our protocol is quite close in terms of the spirit of the original swapping protocol [16,17], but instead of using four photons, we use two photons and the inter-photon entanglement between path and polarization degrees of freedom of each of the photons. A suitable experimental setup involving three Mach-Zehnder interferometers (MZIs) and a few other linear optical devices are used to accomplish this task. Curiously, the photons have never interacted with each other during the whole process of swapping and state transfer. However, the path degrees of freedom of another photon in one of the three MZIs plays a crucial role.

The paper is organized as follows. In Section II, we propose an experimental setup of the entanglement swapping protocol by using simple linear optical devices which allows to swap a path-polarization intra-photon entanglement of single photon onto the polarization-polarization
or path-path intra-photon entanglement between two spatially separated photons. We demonstrate the quantum state transfer protocol in Section III. We provide a brief summary of our results in Section IV.

II. ENTANGLEMENT SWAPPING PROTOCOL

Our experimental setup consists of three suitable MZIs where $MZ_1$ and $MZ_3$ belong to Alice and Bob respectively, and the third interferometer $MZ_2$ is shared by both as shown in the Figure 1. Let us denote the photons in $MZ_1$, $MZ_2$ and $MZ_3$ as ‘1’, ‘2’ and ‘3’ respectively. The entire setup consists of five $50:50$ beam splitters, five polarizing beam splitters, three polarization rotators, eight detectors and two mirrors are denoted by $BS_i$ $(i = 1, 2, 3)$, $PBS_j$ $(j = 1, 2, 3)$, $PR_k$ $(k = 1, 2, 3)$ $D_l$ $(l = 1, 2, 3, 8)$ and $M_m$ $(m = 1, 2)$ respectively.

This arrangement can be considered as a chained Hardy setup [31]. The well-known Hardy setup was originally proposed for demonstrating the non-locality without inequalities. It uses two MZIs, one with electron and other with positron, coupled through a common beam splitter. The positron and electron annihilate if they simultaneously pass through that common beam splitter. This is crucial to produce the non-maximally entangled state required for demonstrating Hardy non-locality. Our setup (Figure 1) is a chained Hardy setups in the sense that $MZ_1$ and $MZ_2$ share the $BS_1$, and $MZ_2$ and $MZ_3$ share the $BS_2$. If electrons pass through the $MZ_1$ and $MZ_3$ and positrons pass through $MZ_2$, then electrons and positrons annihilate at $BS_1$ and $BS_2$. In our setup, we use photons for the implementation of our protocol in which an effect similar to annihilation at $BS_1$ and $BS_2$ is necessary for producing a suitable entangled state required for our purpose. For the case of photons, such effect is obtained by using the bunching of indistinguishable photons. This effect has been extensively discussed in the literature (see, for example,[32, 33]), and also in [34] verifying Hardy paradox experimentally.

The task of our protocol is to generate a polarization-polarization or path-path entangled state between the photons ‘1’ or ‘3’ entering $MZ_1$ and $MZ_3$ respectively while ensuring that they never interact. Further, our goal is to transfer the polarization state $|\chi_1\rangle$ to Bob or $|\chi_3\rangle$ to Alice. Let three photons are allowed to incident simultaneously on the beam splitters $PBS_1$, $PBS_2$ and $PBS_3$ are represented by the quantum states $|\psi\rangle$, $|A\rangle$ and $|\phi\rangle$ respectively, so that, the initial state of the three photons is $|\Psi\rangle = |\psi\rangle \otimes |A\rangle \otimes |\phi\rangle$. We also assume that polarization states of the photons ‘1’, ‘2’ and ‘3’ are $|\chi_1\rangle = a|H_1\rangle + b|V_1\rangle$, $|\chi_2\rangle = \frac{c}{\sqrt{2}}(|H_2\rangle + |V_2\rangle)$ and $|\chi_3\rangle = c|H_3\rangle + d|V_3\rangle$ respectively, with $|a|^2 + |b|^2 = |c|^2 + |d|^2 = 1$. However, $|\chi_2\rangle$ does not play any active role in the present context. The total state of the photons ‘1’, ‘2’ and ‘3’ entering the experimental setup is given by $|\Psi\rangle = |\psi\rangle \otimes |\chi_1\rangle \otimes |A\rangle \otimes |\chi_2\rangle \otimes |\phi\rangle \otimes |\chi_3\rangle$ and the total state of the photons emerging from the $PBS_1$, $PBS_2$ and $PBS_3$ is given by

$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|a|\psi_1\rangle |H_1\rangle + ib|\psi_2\rangle |V_1\rangle) \otimes (|A_1\rangle |H_2\rangle + i|A_2\rangle |V_2\rangle)$$

$$\otimes (c|\phi_1\rangle |H_3\rangle + id|\phi_2\rangle |V_3\rangle)$$

(1)

Next, for understanding the operation $M_1$, $BS_1$, $BS_2$ and $M_2$ on photons let us rearrange Eq. (1) in the following way

$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left[ -b|\psi_2\rangle |A_2\rangle |V_2\rangle (c|\phi_1\rangle |H_3\rangle + id|\phi_2\rangle |V_3\rangle) ight]$$

$$+ c(a|\psi_1\rangle |H_1\rangle + ib|\psi_2\rangle |V_1\rangle) |A_1\rangle |H_2\rangle |\phi_1\rangle |H_3\rangle$$

$$+ id(a|\psi_1\rangle |H_1\rangle + ib|\psi_2\rangle |V_1\rangle) |A_1\rangle |H_2\rangle |\phi_2\rangle |V_3\rangle$$

$$+ ia|\psi_1\rangle |H_1\rangle |A_2\rangle |V_2\rangle (c|\phi_1\rangle |H_3\rangle + id|\phi_2\rangle |V_3\rangle) \right]$$

(2a)

$$+ (2b)$$

$$+ (2c)$$

$$+ (2d)$$

Figure 1: (color online) The setup for implementing the swapping of intra-photon path-polarization entanglement of each of the photons ‘1’ and ‘3’ to inter-photon polarization -polarization entanglement between ‘1’ and ‘3’ and for transferring polarization state of photon ‘1’ to photon ‘3’. (Details are given in the text).

In Eq. (2a) two indistinguishable photons $|\psi_2V_1\rangle$ and $|A_2V_2\rangle$ from $PBS_1$ and $PBS_2$ respectively incident simultaneously on $BS_1$ (central beam splitter of $MZ_1$ and $MZ_2$), which results in bunching effect at $BS_1$ like annihilation in the case of electron and positron, $|\psi_2V_1\rangle |A_2V_2\rangle \rightarrow \frac{1}{\sqrt{2}} (2\psi_2V_1 + 2A_2V_2)$. Similarly in
Eq.(2b) indistinguishable photons $|A_1H_2\rangle$ and $|\phi_1H_3\rangle$ from PBS$_2$ and PBS$_3$ respectively simultaneously bunches at $BS_2$ (central beam splitter of $MZ_2$ and $MZ_3$), $|A_1H_2\rangle|\phi_1H_3\rangle \rightarrow \frac{1}{\sqrt{2}}(|2A_1H_2\rangle + |2\phi_1H_3\rangle).$ Then due to bunching effect the terms $|\psi_2V_1\rangle|A_2V_2\rangle$ and $|A_1H_2\rangle|\phi_1H_3\rangle$ are dropped and consequently Eq.(2c) and Eq.(2d).

Next, the term $iad|\psi_1\rangle|H_1\rangle|A_1\rangle|H_2\rangle|\phi_2\rangle|V_3\rangle$ in Eq.(2c) got phase shift of $-i$ due to three reflection at $M_1$, $BS_1$ and $IB_2$ respectively. However, transmission of $|A_1\rangle|H_2\rangle$ at $BS_2$ has been ignored, hence, the amplitude of $iad|\psi_1\rangle|H_1\rangle|A_1\rangle|H_2\rangle|\phi_2\rangle|V_3\rangle$ reduces with the factor of $1/\sqrt{2}$. On the other hand the term $-bd|\psi_2\rangle|V_1\rangle|A_1\rangle|H_2\rangle|\phi_2\rangle|V_3\rangle$ in Eq.(2c) got phase shift of $-i$ due to three reflections at $BS_1$, $BS_2$ and $M_2$ but the amplitude is reduced by the factor of $1/2$ due to ignorance of transmissions of $|\psi_2\rangle|V_1\rangle$ and $|A_1\rangle|H_2\rangle$ at $BS_1$, $BS_2$ respectively. Hence the terms in Eq.(2c) evolves to

$$id(|\psi_1\rangle|H_1\rangle + i|\psi_2\rangle|V_1\rangle)|A_1\rangle|H_2\rangle|\phi_2\rangle|V_3\rangle$$

$$= \frac{i}{\sqrt{2}}[a|\psi_1\rangle|H_1\rangle|A_2\rangle|V_2\rangle|\phi_1\rangle|H_3\rangle$$

$$+ bd|\psi_2\rangle|V_1\rangle|A_1\rangle|H_2\rangle|\phi_2\rangle|V_3\rangle]$$

Similarly the term $iac|\psi_1\rangle|H_1\rangle|A_2\rangle|V_2\rangle|\phi_1\rangle|H_3\rangle$ in Eq.(2c) got phase shift of $-i$ after three reflections at $M_1$, $BS_1$ and $BS_2$. However, due to ignorance of transmissions of $|A_2\rangle|V_2\rangle$ and $|\phi_1\rangle|H_3\rangle$ at $BS_1$ and $BS_2$ respectively overall amplitude is reduced by factor $1/2$. On the other hand the term $-ad|\psi_1\rangle|H_1\rangle|A_2\rangle|V_2\rangle|\phi_2\rangle|V_3\rangle$ in Eq.(2c) shifted by the phase of $-i$ due to three reflection at $M_1$, $BS_1$ and $M_2$, however the amplitude of this term is reduced by $1/\sqrt{2}$ due to ignorance of transmission of $|A_2\rangle|V_2\rangle$ at $BS_1$. The terms of Eq.(2c) after passing through $M_1$, $BS_1$, $BS_2$ and $M_2$ evolves to

$$iac|\psi_1\rangle|H_1\rangle|A_2\rangle|V_2\rangle|c|\phi_1\rangle|H_3\rangle + id|\phi_2\rangle|V_3\rangle$$

$$= \frac{1}{\sqrt{2}}[(ac|\psi_1\rangle|H_1\rangle|A_2\rangle|V_2\rangle|\phi_1\rangle|H_3\rangle$$

$$+ iad|\psi_1\rangle|H_1\rangle|A_2\rangle|V_2\rangle|\phi_2\rangle|V_3\rangle]$$

Now, Eq.(2a,2b,2c,2d) after passing through $M_1$, $BS_1$, $BS_2$ and $M_2$ is given by

$$|\Psi\rangle = N_1[ad\sqrt{2}|\psi_1\rangle|H_1\rangle|A_1\rangle|H_2\rangle|\phi_2\rangle|V_3\rangle$$

$$+ bd|\psi_2\rangle|V_1\rangle|A_1\rangle|H_2\rangle|\phi_2\rangle|V_3\rangle$$

$$+ ac|\psi_1\rangle|H_1\rangle|A_2\rangle|V_2\rangle|\phi_1\rangle|H_3\rangle$$

$$+ iad\sqrt{2}|\psi_1\rangle|H_1\rangle|A_2\rangle|V_2\rangle|\phi_2\rangle|V_3\rangle]$$

where $N_1 = (a^2c^2 + 4a^2d^2 + b^2d^2)^{-1/2}$ is normalized constant. Using the polarization rotator $PR_1$ before $BS_4$ we flip the vertical polarization $|V_2\rangle$ to $|H_2\rangle$, so that final state is given by

$$|\Psi_1\rangle = N_1[ad\sqrt{2}|\psi_1\rangle|H_1\rangle|A_1\rangle|H_2\rangle|\phi_2\rangle|V_3\rangle$$

$$+ bd|\psi_2\rangle|V_1\rangle|A_1\rangle|H_2\rangle|\phi_2\rangle|V_3\rangle$$

$$+ ac|\psi_1\rangle|H_1\rangle|A_2\rangle|H_2\rangle|\phi_1\rangle|H_3\rangle$$

$$+ iad\sqrt{2}|\psi_1\rangle|H_1\rangle|A_2\rangle|H_2\rangle|\phi_2\rangle|V_3\rangle]$$

$$+ bd|\psi_2\rangle|V_1\rangle|A_1\rangle|H_2\rangle|\phi_2\rangle|V_3\rangle]}$$

Let us now consider two cases:

(i) When the state of the photon in the interferometer $MZ_2$ before $BS_4$ is $|A_3\rangle|H_2\rangle = (i|A_1\rangle + |A_2\rangle)|H_2\rangle/\sqrt{2}$ which results in a detection in $D_3$.

(ii) When the state of the photon in $MZ_2$ before $BS_4$ is $|A_4\rangle|H_2\rangle = (i|A_1\rangle - |A_2\rangle)|H_2\rangle/\sqrt{2}$ which results in a different detector at $D_4$.

Ideally, a PBS can be used in place of $BS_5$. But, the polarization $|\chi_2\rangle$ has no role in the protocol, so a normal beam splitter can serve our purpose. In case (i), we end up with a four-qubit GHZ type entangled state of path and polarization degrees of freedom of the photons ‘1’ and ‘3’. The reduced state of the photons ‘1’ and ‘3’ can then be written as

$$|\Psi_2\rangle = N_2(ac|\psi_1\rangle|H_1\rangle|\phi_1\rangle|H_3\rangle + bd|\psi_2\rangle|V_1\rangle|\phi_2\rangle|V_3\rangle)$$

where $N_2 = (a^2c^2 + b^2d^2)^{-1/2}$. We thus prepared an entangled state between the four degrees of freedoms of two photons by introducing constraints in photons path and using a suitable projective measurement on the photon ‘2’ in $MZ_2$. It is to be noted that during the whole process, the photons ‘1’ and ‘3’ in $MZ_1$ and $MZ_3$ respectively have never interacted with each other.

Similarly, for the case(ii), the resulting reduced state of the photons ‘1’ and ‘3’ can be written as

$$|\Psi_3\rangle = N_2'(ac|\psi_1\rangle|H_1\rangle|\phi_1\rangle|H_3\rangle + bd|\psi_2\rangle|V_1\rangle|\phi_2\rangle|V_3\rangle)$$

$$- i2\sqrt{2}(ac|\psi_1\rangle|H_1\rangle|\phi_2\rangle|V_3\rangle)$$

where $N_2' = (a^2c^2 + b^2d^2 + 8a^2d^2)^{-1/2}$. We do not further use the state in Eq.(7) in this paper.

In order to achieve the path-path or polarization-polarization entanglement between the photons ‘1’ and ‘3’, we need to invoke a suitable disentangling process which again requires no direct interaction between the photons in $MZ_1$ and $MZ_3$. For this, we consider the recombination of $|\psi_1\rangle$ and $|\psi_2\rangle$ by the beam splitter $BS_3$, so that $|\psi_1\rangle = \frac{|\psi_3\rangle + i|\psi_4\rangle}{\sqrt{2}}$ and $|\psi_2\rangle = \frac{|\psi_3\rangle + i|\psi_4\rangle}{\sqrt{2}}$. The state after $BS_3$ can then be written as

$$|\Psi_3\rangle = \frac{N_2}{\sqrt{2}}(|\psi_3\rangle(ac|H_1\rangle|\phi_1\rangle|H_3\rangle + bd|V_1\rangle|\phi_2\rangle|V_3\rangle)$$

$$+ |\psi_4\rangle(ia|H_1\rangle|\phi_1\rangle|H_3\rangle + bd|V_1\rangle|\phi_2\rangle|V_3\rangle)$$

Similarly, the beam splitter $BS_5$ recombine the two paths $|\phi_1\rangle = (|\phi_3\rangle + i|\phi_4\rangle)/\sqrt{2}$ and $|\phi_2\rangle = (i|\phi_3\rangle + |\phi_4\rangle)/\sqrt{2}$. Then, the joint state of the photons ‘1’ and
photons. For this, a few small changes need to be ade-

tions’1’ and ‘3’ even when they have never interacted with

demonstrated a state transfer protocol from Bob to Al-

III. QUANTUM STATE TRANSFER

As mentioned before, our setup can also be used for
demonstrating the teleportation of an unknown quantum
state. One may say that it is an obvious fact once we
have generated the entangled state |Ψ_{13}\rangle, the telepor-
tation is one more step. For this, one more qubit needs to
be brought either by Alice or Bob followed by a relevant
Bell-basis measurement. However, it seems interesting if
the polarization state |χ_{1}\rangle belongs to Alice or |χ_{3}\rangle be-

Bob now measures on his photon ‘3’ by using PBS_{4} and
PBS_{5} and detects the photon in four detectors D_{5}, D_{6},
D_{7} and D_{8}. For four outcomes of Bob yield eight dif-
ferent possibilities at Alice’s end. The states of Bob’s pho-
ton corresponding to the detectors D_{5}, D_{6}, D_{7} and D_{8}
are |φ_{3}\rangle|H_{3}\rangle, |φ_{3}\rangle|V_{3}\rangle, |φ_{4}\rangle|H_{3}\rangle and |φ_{4}\rangle|V_{3}\rangle respectively.
The measurements at Bob’s end produce the following
states at Alice’s end are given by

\begin{align}
|\Psi_{D_{5}}\rangle &= \frac{N_{2}}{2\sqrt{2}} \left[ \left| \psi_{3} \right\rangle (ac|H_{1}\rangle - bd|V_{1}\rangle) |φ_{3}\rangle |H_{3}\rangle + (ac|H_{1}\rangle + bd|V_{1}\rangle) |φ_{4}\rangle |V_{3}\rangle \right] + \left| \psi_{4} \right\rangle (ac|H_{1}\rangle + bd|V_{1}\rangle) |φ_{4}\rangle |V_{3}\rangle \right] \\
|\Psi_{D_{6}}\rangle &= \frac{N_{2}}{2\sqrt{2}} \left[ \left| \psi_{3} \right\rangle (ac|H_{1}\rangle + bd|V_{1}\rangle) |φ_{3}\rangle |H_{3}\rangle + (ac|H_{1}\rangle - bd|V_{1}\rangle) |φ_{4}\rangle |V_{3}\rangle \right] + \left| \psi_{4} \right\rangle (ac|H_{1}\rangle - bd|V_{1}\rangle) |φ_{4}\rangle |V_{3}\rangle \right] \\
|\Psi_{D_{7}}\rangle &= \frac{N_{2}}{2\sqrt{2}} \left[ \left| \psi_{3} \right\rangle (ac|H_{1}\rangle + bd|V_{1}\rangle) |φ_{3}\rangle |H_{3}\rangle + (ac|H_{1}\rangle - bd|V_{1}\rangle) |φ_{4}\rangle |V_{3}\rangle \right] + \left| \psi_{4} \right\rangle (ac|H_{1}\rangle - bd|V_{1}\rangle) |φ_{4}\rangle |V_{3}\rangle \right] \\
|\Psi_{D_{8}}\rangle &= \frac{N_{2}}{2\sqrt{2}} \left[ \left| \psi_{3} \right\rangle (ac|H_{1}\rangle + bd|V_{1}\rangle) |φ_{3}\rangle |H_{3}\rangle + (ac|H_{1}\rangle - bd|V_{1}\rangle) |φ_{4}\rangle |V_{3}\rangle \right] + \left| \psi_{4} \right\rangle (ac|H_{1}\rangle - bd|V_{1}\rangle) |φ_{4}\rangle |V_{3}\rangle \right] \\
\end{align}

Note here that |Ψ_{D_{5}}\rangle = |Ψ_{D_{6}}\rangle and |Ψ_{D_{7}}\rangle = |Ψ_{D_{8}}\rangle. Let
us now assume that a = b = 1/\sqrt{2}. Then after the de-
tection of photon ‘3’ in four different detectors (D_{5}, D_{6}, D_{7}
and D_{8}), Bob needs to send the information through a
classical communication channel. Following Bob’s in-
struction, Alice performs suitable gate operations to ob-
tain the desired state |χ'_{3}\rangle = c|H_{1}\rangle + d|V_{1}\rangle as given in
the Table-1. Then, whenever Bob gets photon ‘3’ in D_{5}
or in D_{8}, he asks Alice to use a Pauli gate σ_{z} in the
channel |ψ_{3}\rangle. If he gets the photon in D_{6} or in D_{7}, Al-
ice has to use the σ_{z} in the channel |ψ_{4}\rangle. Hence, we
demonstrated a state transfer protocol from Bob to Al-
ice without any direct interaction between photons ‘1’ and
‘3’ in two interferometers MZ_{1} and MZ_{3}. Note that the
success probability of teleportation in this case is 1/8, i.e.,
the cost of the state transfer is larger than the orig-
nal teleportation protocol. Importantly, no Bell-basis
measurement is required in the whole process.
Table I: Alice’s unitary rotation on the path $|\psi_3\rangle$ and $|\psi_4\rangle$ upon receiving instructions from Bob.

| Bob’s detection | Alice’s operation on $|\psi_3\rangle$ | Alice’s operation on $|\psi_4\rangle$ |
|-----------------|--------------------------------------|--------------------------------------|
| $D_5$           | $\hat{\sigma}_Z$                     | $I$                                  |
| $D_6$           | $I$                                  | $\hat{\sigma}_Z$                     |
| $D_7$           | $I$                                  | $\hat{\sigma}_Z$                     |
| $D_8$           | $\hat{\sigma}_Z$                     | $I$                                  |

IV. DISCUSSION

We have demonstrated an interesting swapping protocol using simple linear optical devices where the intraphoton entanglement between path and polarization degrees of freedom of a single photon is swapped to polarization-polarization entanglement of two spatially separated photons. Note that, those photons have never interacted during the whole process. We have further shown how the same setup can be used for the purpose of a curious quantum state transfer. Both the protocols avoid Bell basis discrimination which is taken care by exploiting the actions of the path degrees of freedoms in $MZ_1$ and $MZ_3$. We believe that the proposed setup can be experimentally implemented with the existing technology that uses linear optical devices.

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