EAST EUROPEAN JOURNAL OF PHYSICS. **3.** 39-44 (2022)
DOI:10.26565/2312-4334-2022-3-05 ISSN 2312-4334

ENTANGLED COHERENT STATES IN TELEPORTATION[†]

Shivani A. Kumar*, Shefali Kanwar, Pramila Shukla
Amity Institute of Applied Sciences, Amity University, Noida, India
**Corresponding Author: shivani_v11@rediffmail.com*

Received June 7, 2022; revised June 13, 2022; accepted June 22, 2022

In the present paper, we will review the methods to produce superposition of entangled coherent state using polarizing beam splitter and Kerr non linearity. These coherent states have many attractive features and can be used in various schemes. Entanglement, refers to the superposition of a multiparticle system and explains a new type of correlations between any two subsystems of the quantum system, which is not existing in the classical physics. The present paper deals with the use of these states in quantum teleportation, entanglement diversion and entanglement swapping schemes. Entanglement diversion and entanglement-swapping refers to a scheme which may entangle those particles which had never interacted before. In the swapping scheme, two pairs of entangled state are taken. One particle from each pair is subjected to a Bell-state-measurement. This would result in projection of the other two outgoing particles in an entangled pair. Quantum Teleportation of two mode and three modes states is also studied with perfect fidelity. Minimum assured fidelity which is defined as the minimum of the fidelity for any unknown quantum information of the states is also discussed. It is also shown how the success rate of teleportation of a superposition of odd and even coherent states can be increased from 50% to almost 100%. The scheme suggested by van Enk and Hirota was modified by Prakash, Chandra, Prakash and Shivani in 2007. We find that an almost teleportation, diversion and swapping is possible by simply separating vacuum state from the even state. The present paper also deals with study of effect of decoherence and noise on these states and the effect of noise on fidelity and minimum assured fidelity. It is also discussed that these schemes can also be applied to the process of entanglement diversion and entanglement swapping.

Keywords: Entanglement, teleportation, fidelity, coherent state
PACS: 03.67. Hk, 03.65. Ud, 03.67. Lx

INTRODUCTION

The most important feature of the quantum optics is the study of the effects of the interaction between atoms and laser fields, and most of the issues with a specific set of quantum states for the description of the area, as well as the atoms[1,2]. They are referred to as coherent-states, and it can be used in the problem of the sub-areas of interaction. These states are commonly referred to as the Glauber states [3-5], and in honor of that, the American scientist who is, for the first time, we realized that in their good use for the description of optical phenomena. These proposals are currently being intensively studied and applied to the quantum-optical problems. The explicit form of states in question is,

$$|\alpha\rangle=\sum_{n=0}^{\infty}e^{-\frac{1}{2}|\alpha|^2}\frac{\alpha^n}{\sqrt{n!}}|n\rangle \tag{1}$$

where the Fock-states [6] $|n\rangle$ is eigen-state of the number operator $N=a^{\dagger}a$, i.e., $N|n\rangle=n|n\rangle$ and $\alpha=\alpha_r+i\alpha_i$ is complex number.

Sudarshan [7] and Glauber also provided a diagonal representation independently for the density operator of the radiation in point of coherent-states. Coherent-state is a pure state and also it is not a non-diagonal state. Superposition which includes the superposition of any two or more than two coherent-states are non-classical. Numerous possibilities for generation of the non-classical-state of the electromagnetic field has also been presented [8, 9].

However, whenever we are considering the class of the states including the superposition of any two coherent-states of an equal amplitude and are separated by phase of 180°, i.e. states takes the form

$$|\psi\rangle=\frac{1}{\sqrt{N_z}}\Big[\,|\beta\rangle\pm e^{i\theta}|-\beta\rangle\Big] \tag{2}$$

Here, the normalization constant N_z is given as,

$$N_z=2+2e^{-2|\beta|^2}\cos\theta\,, \tag{3}$$

For large $|\beta|$, states $|\beta\rangle$ and $|-\beta\rangle$ are very much macroscopically distinguishable. The and superposition state of the form in equation (2) is termed as the Schrodinger's-cat-states [10]. One of very initial treatments for producing this superposition of the states were given by scientists Yurke & Stoler who demonstrated generation of a coherent-superposition of the state of the form

---

[†] ***Cite as***: S.A. Kumar, S. Kanwar, and P. Shukla, East Eur. J. Phys. **3**, 39 (2022), https://doi.org/10.26565/2312-4334-2022-3-05

$$|\,\psi\,\rangle = \frac{1}{\sqrt{2}}\Big[\,|\,\alpha\,\rangle + e^{i\pi/2}\,|-\alpha\,\rangle\,\Big], \tag{4}$$

using a Kerr nonlinearity.

Tara et al. [11] showed generation of Schrodinger-macroscopic-quantum superposed states in an optical Kerr non-linear medium. The authors also presented a scheme for generation of superposed squeezed-coherent-states. In 1996, C.C. Gerry presented a scheme to generate Schrodinger-cat-states as well as the entangled-coherent-states by dispersive interaction inside a trapped ion. The author demonstrated that the entangled-coherent-states may be produced which are a general form of Schrodinger-cat-state giving some very strong correlations between different output modes.

In 1999, a famous researcher Gerry [12,13] presented a scheme to produce Schrodinger-cat-states. Recently, Kim & Paternostro [12] also presented a method to generate superposed coherent-states with the help of small Kerr-non linearity effect and single photon or even two entangled-twin-photons. However, both of the above-mentioned authors in the references [11] and [12,13] had used cross Kerr nonlinearity whose evolution operator is shown as $\hat{U}_{CK} = \exp\left(-i\,\chi\,\hat{n}_a\hat{n}_b\right)$. This may affect the phase of the system which depends on the photon-numbers of the output two modes a & b. Here, $\hat{n}_b$ is termed as photon-number operator for the output mode b. If the mode a is in the coherent-state of its amplitude α & the mode b is in the single photon state, then using the action of the cross Kerr-nonlinearity,

$$\hat{U}_{CK}\,|\,\alpha\,\rangle_a\,|\,n\,\rangle_b = \left|\,\alpha\, e^{i n_b \chi t}\right\rangle_a |\,n\,\rangle_b\,, \tag{5}$$

here, the Fock state $|\,\mathrm{n}\,\rangle_{\mathrm{b}}$ remains unaffected with interaction. However, the coherent state $|\,\alpha\,\rangle_a$ takes a phase shift which is directly proportional to the photon-number n_b in the state $|\,n\,\rangle_b$.

Recently Hari Prakash and coauthors [14,15] presented a method for generating a general superposition of the coherent-states $|\,\alpha\,\rangle$ and $|-\alpha\,\rangle$ taking the action of Kerr effect into account. Their method involved two beams in coherent-states, a single photon-beam and some linear optical devices such as polarization beam-splitter & mirrors. The authors showed that, if a single photon beam is obtained in the output mode in a desired polarization state which is defined by the angles θ & ϕ , the this results in a definite superposed coherent-states $|\,\alpha\,\rangle$ and $|-\alpha\,\rangle$. If any photon is obtained in any orthogonal state of polarization, this results in a superposition which is different from desired one.

These macroscopic superposition of coherent-states have been shown to possess various important non-classical properties. For example, a Schrodinger cat state of the form

$$|\,\psi\,\rangle = c_1\left|\,\alpha e^{i\theta}\right\rangle + c_2\left|\,\alpha e^{-i\theta}\right\rangle \tag{6}$$

is known to lead a squeezed state, normal 2nd order squeezing, higher-order squeezing & sub-poissonian statistics and other non-classical properties of the field.

Entanglement

Entanglement, is a simple name given for the superposition of a multiparticle system. It is one of a most important aspects of quantum mechanics. It explains a new type of correlations between any two subsystem of the quantum system, which is not existing in the classical physics. This word is the translation of a German word "Verschränktheit". It is first noted by Schrödinger in his paper. Both the words have notation of the word "contortedness", which demonstrates the efforts of understanding such correlations in classical terms. However, from this point of view of the Quantum Theory, such correlations very straightforward.

An entangled, composite quantum system is divided into separate sub-systems, which are closely related to each other, even if they're far away from each other and do not interact with each other. If a measurement is carried out in one of the sub-systems, it has an effect on the results of the measurements carried out in the other sub-system. This feature is in a contradiction with local realism, i.e., the statement that the quantum states of spatially-separated, non-interacting particles are independent of each other. This phenomenon has been discussed by Einstein-Podolsky-Rosen (EPR) in 1935, in their initial paper. Their paper was the attempt to explain that quantum mechanics is an incomplete mechanics. EPR explained as the starting point premises of “reality” and a “no-action-at-a-distance”. It is many times termed as locality. In their paper, “local realism” is explained as a dual premise, in which both the realism as well as the locality is assumed. In this reply Schrodinger introduced the concept of entangled quantum states, pointing to entanglement as a signature of states not compatible with classic notions, such as local realism. Schrodinger’s reply is best known for his discussion of paradox of macrospically-entangled state, a “cat” in a quantum superposition of “alive” or “dead” states.

COMPUTATIONAL DETAILS

In the present paper, we have studied various aspects of entanglement such as teleportation, entanglement diversion and entanglement swapping. The success of teleportation is measured by calculating fidelity. This paper focusses on fidelity also.

Quantum Teleportation

Another important application of quantum entanglement, in correlation with quantum information processing, is termed as "***quantum teleportation*".** In teleportation, an unknown quantum state is being transferred from one location to another, which are widely separated. Quantum teleportation involves transferring complete information of one quantum state from one location to another location with aid of long-range E-P-R correlations in an entangled-state. This state is shared between the two parties which are known as the sender and the receiver. At first, the sender makes some measurements with the information states and her/his shared part of the entangled state. In this process, the information state disappears at the sender's end and instantaneously appears at the receiver's end. This is obtained when the receiver makes some unitary transformation which depends on some result of the sender's measurement which is received through some classical channel. The process of teleportation somewhat resembles with the teleportation which had read in the science fiction (Shaktimaan) where one person or an object disappears at the sender's place while an exact replica of the same person reappears at some other place. However, this replica is not generated instantaneously and that for making replica a classical information is required.

Suppose transfer of an unknown qubit of some quantum information is required from one party, whom we call as ***Alex**,* to another party called as ***Bobby.*** Alex and Bobby do not directly exchange any quantum system by any means carrying any information. This means that they do not share any quantum channel which is common for both the parties. Alex can try to find some qubit so as to obtain the classical information, which she will convey to Bobby via some classical channel. Based on the information received from Alex, Bobby will then try to reconstruct the original state again. Bennett and coauthors [16] proposed ***teleportation*** which allows Alex and Bobby to transfer a quantum state perfectly from one point to another provided that both the parties share one-half part of an entangled pair of particles. Now Alex would find the unknown qubit of her part of the entangled pair in a particular basis. She then conveys the outcome of her measurement results to Bobby. After that, Bobby collects necessary information to again reconstruct the original state from his share of the entangled pair.

Fidelity

The efficiency of teleportation is determined by measuring ***fidelity***. The fidelity of the teleportation is defined by overlap of the input information state with the (normalized) output teleported state. It also gives a measure of the quality of the teleported state. By determining the overlap between the input information state $|\psi\rangle$ and the teleported output state, ρ, i.e.

$$F = \langle \psi | \rho | \psi \rangle \tag{7}$$

If the output state is exactly same as the input information state, then the fidelity of the teleportation is equal to unity.

Fidelity is state dependent, i.e., the fidelity of the reconstructed state depends both on the quality of the teleporter and on the class of input states from which the unknown state is picked. However, some authors have defined the fidelity as

$$F = Tr\left[\rho_{out} | \varphi \rangle \langle \varphi | \right] \tag{8}$$

When ρ_{out} is an exact replica of $|\varphi\rangle$, then $F = 1$, and when ρ_{out} is an imprecise copy of $|\varphi\rangle$, then $F < 1$. Finally when ρ_{out} is completely orthogonal to the state $|\varphi\rangle$, the fidelity is zero and the teleportation is not possible. If $|I\rangle$ represents the information state, to be teleported, and $|T\rangle$ represents the teleported copy of the initial information state that Bobby has in his hand after application of the unitary transformation, then fidelity of the teleported state is calculated by using, $\rho_{out} = |T\rangle\langle T|$ which gives,

$$F = \langle T | I \rangle \langle I | T \rangle . \tag{9}$$

In a paper van Enk and Hirota [17] gave a scheme to teleport one bit of quantum information contained in a superposition of even and odd coherent-states. They used entangled-coherent-states, a beam splitter and two-phase shifters. X. Wang [18,19] also presented a scheme of teleportation of 1 bit of information contained in bipartite superposed entangled coherent state using a tripartite entangled coherent state, similar to the scheme of van Enk and Hirota. N. Ba An [20] presented a scheme to teleport a single particle state using a four-partite state, a beam-splitter and two phase-shifters.

Recently quantum teleportation has been demonstrated experimentally using parametric down conversion in interferometric Bell state analyzers. Quantum teleportation of states with continuous degree of freedom has been demonstrated both experimentally and theoretically. Teleportation of continuous variables can be described in two different ways, one in terms of Wigner functions, the other in terms of discrete basis states. Also, the efficiency of teleportation of discrete and continuous observable was tested directly with the help of Mach Zehnder interferometer. These entangled-coherent-states play a very important role in teleportation. However, Fan and Lu An. [21-23] have used the terminology "coherent entangled states" which is completely different from "entangled coherent state".

Entanglement Diversion

Another field in which entanglement plays a very important role is ***entanglement diversion*** which was originally presented by C. Xin-Hua and coauthors [24]. He involved three remote parties, Alex, Bobby and Charlie. Out of these three parties, Alex is connected to Bobby and Charlie both by sharing an entangled state involving two modes. Here, the diversion scheme connects Bobby and Charlie which were not connected by sharing any entangled two mode state.

In recent years, however, entanglement has aroused much interest in the quantum information processing such as quantum computation, quantum dense coding and quantum cryptography quantum-telecloning, entanglement-purification and quantum-error-corrections.

Entanglement Swapping

A similar concept is ***entanglement-swapping***. This is a scheme which may entangle those particles which had never interacted before. In the swapping scheme, two pairs of entangled state are taken. One particle from each pair is subjected to a Bell-state-measurement. This would result in projection of the other two outgoing particles in an entangled pair. This scheme was first demonstrated by Zukowski and his coauthors [25]. In their scheme, the authors used two parametric-down-converters, each of which emitted a photon pair. This resulted in entangling the other two initially independent photons by coincident registration of idlers. the first experimental realization of entanglement swapping was reported by Pan et al. [26, 27] and others.. The scheme was generalized to multiparticle system by Zeilinger et al. [28,29] and some other authors, and Bose et al. [30]. Entanglement swapping scheme for multi-qudit system was first given by Bose and his coauthors, and for continuous variables, it has been shown experimentally. It has also been demonstrated that in any two partially entangled states, entanglement swapping yields the weaker entanglement of the two.

A scheme of teleporting a superposed coherent-states $|\alpha\rangle$ and $|-\alpha\rangle$ with the help of beam-splitter and two phase-shifters was done. The authors obtained an near perfect teleportation for an appreciable mean photon-numbers. They also calculated the minimum of the average fidelity and showed that for $|\alpha|^2 = 5$, the minimum of the average fidelity is 0.9999. At the end they conclude that, the scheme leads to a near perfect successful teleportation for some appreciable photons. The authors wrote coherent state $|\alpha\rangle$ in terms of the even and the odd coherent state [31-39],

$$|\,EVEN\,/\,ODD,\alpha\rangle = \frac{|\alpha\rangle \pm |-\alpha\rangle}{\sqrt{2\left(1 \pm x^2\right)}}, \quad x \equiv e^{-|\alpha|^2} \tag{10}$$

The authors separated $|\,EVEN,\alpha\rangle$ as the superposition of vacuum state $|0\rangle$ and the non-zero -even photon state $|\,NZE,\alpha\rangle$ [75-84] and wrote

$$|\pm\alpha\rangle = \sqrt{x}\;|0\rangle + 2^{-1/2}(1-x)\,|\,NZE,\,\alpha\rangle \pm [(1/2)(1-x^2)]^{1/2}\,|\,ODD,\,\alpha\rangle, \tag{11}$$

where

$$|\,NZE,\,\alpha\rangle = \left(|\,\alpha\rangle + |-\alpha\rangle - 2\sqrt{x}\,|\,0\rangle\right)/\sqrt{2}\left(1-x\right). \tag{12}$$

A scheme of teleporting bipartite entangled-coherent-states including tripartite entangled-coherent-states, beam-splitters and phase-shifters was also presented. We concluded that a near-to-perfect teleportation may be obtained when an appreciable mean-number of photons were present in the output. Here also we find the minimum of the average fidelity and showed that it is 0.9999 even if $|\alpha|^2 = 5$. Thus, an almost perfect teleportation can be achieved even if mean number of photons is quite low. We again discuss the impact of the noise (decoherence) on the fidelity in the scheme of the teleportation in this context.

Another scheme of teleporting a superposition of the even and the odd coherent-states involving a 4-partite entangled-coherent-states, and linear devices such as beam- splitters and phase-shifters. This scheme, was dealt with a system comprising four partners: Alex, Bobby, Charlie and David. We calculated a near-to- perfect teleportation if an appreciable mean-number of photons were found. Here also we calculated the minimum of the average-fidelity (MAF) and find that it is 0.9999 for $|\alpha|^2 = 5$.

Entanglement-diversion is discussed between two entangled-coherent-states. This is a scheme in which the entanglement of entangled-coherent-states is diverted. In this diversion scheme, there are any three distant partners named as: Alex, Bobby and Charlie. Alex and Bobby are connected with each other by sharing a quantum channel $|\Phi\rangle_{13}$ of the state in mode 1 which is with Alex and the state in mode 3 which is with Bobby. Alex and Charlie are also connected with each other by sharing another quantum channel $|\Phi\rangle_{24}$ of the state in the mode 2 which is with Alex and the state in the mode 4 which is with Charlie. These connected partners may take the help of entangled-states of the shared quantum channel. It may be used to teleport the quantum channel between them. Through entanglement-diversion-scheme, Bobby and Charlie will also develop a very direct connection between them. The authors, find that a near-to-perfect diversion may be achieved if an appreciable mean-number of photons are present.

Entanglement-swapping between two imperfectly entangled-coherent-states. Our proposal involves a beam-splitter and optical instruments like two-phase-shifters. A near-to-perfect swapping may be possible for an appreciable mean number of photons.

RESULT AND DISCUSSION

Superposition of an entangled-coherent-states can be produced using the process of Kerr-nonlinearity. These coherent-states play a very vital role in the quantum teleportation of entangled coherent state, whether it is single particle system or a multiparticle system. They also can be used to produce the scheme of entanglement diversion and entanglement-swapping schemes. By separating non zero even state from vacuum state, an almost perfect teleportation, diversion or swapping can be achieved which can be verified by calculating the fidelity of the final achieved state.

Acknowledgement

The authors are extremely grateful to Amity University, Noida.

ORCID IDs

Shivani A. Kumar, https://orcid.org/0000-0003-0200-9570; **Shefali Kanwar,** https://orcid.org/0000-0002-8869-2165
Pramila Shukla, https://orcid.org/0000-0002-7786-6510

REFERENCES

[1] P. Shukla, S.A. Kumar, and S. Kanwar, "Interaction of Light with matter: nonclassical phenomenon", Physics and Chemistry of Solid State, **23**(1), 5-15, 2022, https://doi.org/10.15330/pcss.23.1.5-15

[2] E. Schrodinger, "An undulatory theory of the mechanics of atoms and molecules", Phys. Rev. **28**, 1049-1054 (1926), https://doi.org/10.1103/PhysRev.28.1049

[3] R.J. Glauber, "The Quantum Theory of Optical Coherence", Phys. Rev. **130**, 2529-2536 (1963), https://doi.org/10.1103/PhysRev.130.2529

[4] R.J. Glauber, "Coherent and Incoherent States of the Radiation Field", Phys. Rev. **131**, 2766-2772 (1963), https://doi.org/10.1103/PhysRev.131.2766

[5] R.J. Glauber, *In Quantum Optics and Electronics*, edited by C. De Witt, A. Blandin and C. Cohen-Tanaudiji, (Gordon and Breach, New York, 1965)

[6] V. Fock, „Verallgemeinerung und Lösung der Diracschen statistischen Gleichung", Z. Phys. **49**, 339-351 (1928), https://doi.org/10.1007/BF01337923

[7] E.C.G. Sudarshan, "Equivalence of Semiclassical and Quantum Mechanical Descriptions of Statistical Light Beams", Phys. Rev. Lett. **10**, 277-286 (1963), https://doi.org/10.1103/PhysRevLett.10.277

[8] D. Stoler, B.E.A. Saleh, and M.C. Teich, "Binomial States of the Quantized Radiation Field", Opt. Acta, **32**, 345 (1985), https://doi.org/10.1364/JOSAB.4.000185;

[9] B. Yurke, and D. Stoler, "Generating Quantum Mechanical Supoerpositions of Macroscopically Distinguishable States via Amplitude Dispersion", Phys. Rev. Lett. **57**, 13-18 (1986), https://doi.org/10.1103/PhysRevLett.57.13

[10] C.C. Gerry, "Generation of Schrodinger cats and entangled-coherent-states in the motion of a trapped ion by a dispersive interaction", Phys. Rev. A, **55**, 2479-2487 (1996), https://doi.org/10.1103/PhysRevA.55.2478

[11] K. Tara, G.S. Agarwal, and S. Chaturvedi, "Production of Schrodinger macroscopic quantum superposition states in a Kerr medium", Phys. Rev. A, **47**, 5024-5031 (1993), https://doi.org/10.1103/PhysRevA.47.5024

[12] C.C. Gerry, "Generation of optical macroscopic quantum superposition states via state reduction with a Mach-Zehnder interferometer containing a Kerr medium", Phys. Rev. A, **59**, 4095-4103 (1999), https://doi.org/10.1103/PhysRevA.59.4095

[13] M.S. Kim, and M. Paternostro, "Generation of a coherent superposition state on demand", https://arxiv.org/abs/quant-ph/0510057

[14] S.A. Kumar, H. Prakash, N. Chandra, and R. Prakash, "Production of Superposition of Coherent-states Using kerr Non-Linearity", Springer Proceedings in Physics, **256**, 117-126, (2020), https://doi.org/10.1007/978-981-15-8625-5_13

[15] Shivani. A. Kumar, "Quantum teleportation of a tripartite entangled coherent state", Modern Physics Letters A, **36 (31)**, 2150217-2150227, 2021, https://doi.org/10.1142/S0217732321502175

[16] C.H. Bennett, G. Brassard, C. Crepeau, R. Jozsa, A. Peres, and W.K. Wootters, "Teleporting an Unknown Quantum State via Dual Classical and Einstein-Podolsky-Rosen Channels", Phys. Rev. Lett. **70**, 1895 (1993), https://doi.org/10.1103/PhysRevLett.70.1895

[17] S.J. van Enk, and O. Hirota, "Entangled-coherent-states: Teleportation and decoherence", Phys. Rev. A, **64**, 022313 (2001), https://doi.org/10.1103/PhysRevA.64.022313

[18] X. Wang, "Quantum teleportation of entangled-coherent-states, Phys. Rev. A", **64**, 022302 (2001), https://doi.org/10.1103/PhysRevA.64.022302

[19] Parakh, A. "Quantum teleportation with one classical bit", Scientific Reports, **12**(1) 3392, (2022), https://doi.org/10.1038/s41598-022-06853-w

[20] N.B. An, "Teleportation of coherent-state superpositions within a network", Phys. Rev. A, **68**, 022321-022329 (2003), https://doi.org/10.1103/PhysRevA.68.022321

[21] H.Y. Fan, and H.L. An, "New two-mode coherent-entangled state and its application", J. Phys. A, **37**, 10993-10997 (2004), https://doi.org/10.1088/0305-4470/37/45/017

[22] M. Swathi, and B. Rudra, "An efficient approach for quantum entanglement purification", International Journal of Quantum Information, **20**(4), 225004, (2022), https://doi.org/doi:10.1142/S0219749922500046

[23] S. Banerjee, A. Patel, and P. Panigrahi, “Minimum distance of the boundary of the set of PPT states from the maximally mixed state using the geometry of the positive semidefinite cone”, Quantum Inf. Process **18**, 296 (2019). https://doi.org/10.1007/s11128-019-2411-6
[24] C.X. Hua, G.J. Rong, N.J. Jun, and J.J. Ping, “Entanglement diversion andquantum teleportation of entangled-coherent-states”, Chinese Physics, **15**, 488 (2006), https://doi.org/10.1088/1009-1963/15/3/006
[25] M. Zukowski, A. Zeilinger, M.A. Horne, and A.K. Ekert. “Event-Ready-Detectors” Bell Experiment via Entanglement swapping Phys. Rev. Lett. **71**, 4287-4295 (1993), https://doi.org/10.1103/PhysRevLett.71.4287
[26] J.W. Pan, D. Bouwmeester, H. Weinfurter, and A. Zeilinger, “Experimental Entanglement Swapping: Entangling Photons That Never Interacted”, Phys. Rev. Lett. **80**, 3891-3899 (1998), https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.80.3891
[27] K.G. Paulson, and P.K. Panigrahi, “Tripartite non-maximally-entangled mixed states as a resource for optimally controlled quantum teleportation fidelity, Physical Review A, **100**(5), 052325 (2019), https://doi.org/10.1103/PhysRevA.100.052325
[28] A. Zeilinger, M.A. Horne, H. Weinfurter, and M. Zukowski, “Three-Particle Entanglement from Two Entangled Pairs”, Phys. Rev. Lett. **78**, 3031-3038 (1997), https://doi.org/10.1103/PhysRevLett.78.3031
[29] J. I. de Vicente, C. Spee, D. Sauerwein, and B. Kraus, “Entanglement manipulation of multipartite pure states with finite rounds of classical communication”, Phys. Rev. A 95, 012323 (2017), https://doi.org/10.1103/PhysRevA.95.012323
[30] S. Bose, V. Vedral, and P.L. Knight, “Multiparticle generalization of entanglement swapping”, Phys. Rev. A, **57**, 822-831 (1998), https://doi.org/10.1103/PhysRevA.57.822
[31] S. Bose, V. Vedral, and P.L. Knight, “Purification via entanglement swapping and conserved entanglement”, Phys. Rev. A, **60**, 194-201 (1999), https://doi.org/10.1103/PhysRevA.60.194
[32] H. Prakash, N. Chandra, R. Prakash, and Shivani, “Improving the teleportation of entangled-coherent-states”, Phys. Rev. A, **75**, 044305-044315 (2007), https://doi.org/10.1103/PhysRevA.75.044305
[33] H. Prakash, N. Chandra, R. Prakash, and Shivani, “Effect of decoherence on fidelity in teleportation using entangled-coherent-states”, Journal of Physics B: Atomic, Molecular and Optical Physics, **40**(8), 1613–1626 (2007), https://doi.org/10.1088/0953-4075/40/8/012
[34] H. Prakash, N. Chandra, R. Prakash, and Shivani, “Effect of decoherence on fidelity in teleportation of entangled-coherent-states”, International Journal of Quantum Information, **6**(5), 1077–1092 (2008), https://doi.org/10.1142/S0219749908004213
[35] H. Prakash, N. Chandra, R. Prakash, and S.A. Kumar, “Entanglement diversion between two pairs of entangled-coherent-states”, International Journal of Modern Physics B, **23**(4), 585–595 (2009), https://doi.org/10.1142/S0217979209049930
[36] H. Prakash, N. Chandra, R. Prakash, and Shivani, “Swapping between two pairs of nonorthogonal entangled-coherent-states”, International Journal of Modern Physics B, **23**(8), 2083–2092 (2009), https://doi.org/10.1142/S0217979209052042
[37] H. Prakash, N. Chandra, R. Prakash, and Shivani, “Almost perfect teleportation using 4-partite entangled states”, International Journal of Modern Physics B, **24**(17), 3383–3394 (2010), https://doi.org/10.1142/S0217979210053367
[38] H. Prakash, N. Chandra, R. Prakash, and S.A. Kumar, “Improving the entanglement diversion between two pairs of entangled-coherent-states”, International Journal of Modern Physics B, **24**(17), 3331–3339 (2010), https://doi.org/10.1142/S0217979210053331
[39] S.A. Kumar, in: *International Conference on Fibre Optics and Photonics*, OSA Technical Digest (online) (Optica Publishing Group, 2012), paper WPo.8, https://opg.optica.org/abstract.cfm?URI=Photonics-2012-WPo.8
[40] S.A. Kumar, H. Prakash, N. Chandra, R. Prakash, “Noise in swapping between two pairs of non-orthogonal entangled-coherent-states”, Modern Physics Letters B, **27**(3), 1350017 (2013), https://doi.org/10.1142/S0217984913500176

ЗПЛУТАНІ КОГЕРЕНТНІ СТАНИ В ТЕЛЕПОРТАЦІЇ

Шивані А. Кумар, Шефалі Канвар, Праміла Шукла
Інститут прикладних наук Аміті, Університет Аміті, Нойда, Індія

У цій роботі ми розглянемо методи створення суперпозиції зплутаного когерентного стану з використанням поляризаційного розділювача пучка та нелінійності Керра. Ці когерентні стани мають багато привабливих рис і можуть бути використані в різних схемах. Зплутаність відноситься до суперпозиції багаточасткової системи і пояснює новий тип кореляцій між будь-якими двома підсистемами квантової системи, який не існує в класичній фізиці. У цій роботі йдеться про використання цих станів у квантовій телепортації, схемах відхилення зплутаності та заміна заплутування. Відхилення зплутаності та заміна заплутування відносяться до схеми, яка може зплутати ті частки, які ніколи раніше не взаємодіяли. У схемі зплутаності йдеться про дві пари зплутаного стану. Одна частка з кожної пари піддається виміру стану Белла. Це може призвести до відбиття у зплутаній парі двох інших часток, які виходять, Квантова телепортація дво-режимних і трьох-режимних станів також вивчається з ідеальною точністю. Також обговорюється мінімальна гарантована точність, яка визначається як мінімум точності для будь-якої невідомої квантової інформації про стани. Також показано, як рівень швидкості телепортації суперпозиції парних і непарних когерентних станів може бути збільшена з 50% до майже 100%. Схема, запропонована ван Енком і Хіротою, була модифікована Пракашем, Чандрою, Пракашем і Шівані у 2007 році. Ми виявили, що майже повна телепортація, відхілення та заміна можуть бути здійсненими шляхом простого відокремлення стану вакууму від парного стану. У цій роботі також йдеться про вплив декогерентності та шуму на ці стани, а також про вплив шуму на точність та мінімальну гарантовану точність. Також обговорюється, що ці схеми також можуть бути застосовані до процесу відхілення зплутаності та заміни заплутування.

Ключові слова: зплутаність, телепортація, точність, когерентний стан