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A review on the future of optical communication using twist in the light

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***Abstract* - Day by day, the demand for high data rates is rising. The information-carrying capacity of a traditional transmission system needs to be increased. For the transport of twisted light, optical fibers, which are one of the most common data transmission media, can be used. Twisted light stands for photons that have an orbital angular momentum called quantum characteristics. OAM photons have electric and magnetic fields that corkscrew instead of oscillating in a plane. There are potentially infinite numbers of OAM values, and then the same fiber can be occupied by several beams with different orbital angular momentums, allowing more data to be transferred.**

***Index Terms* - Fiber communication, Orbital Angular Momentum, Optic communication, Twisted Light.**

I.INTRODUCTION

A new fiber-optic cable that seamlessly switches several light beams simultaneously could dramatically speed up the transmission of data over the Internet. Without simply laying more fibers, it's like making more fibers. Via a single fiber, it can dispatch different beams of light. The concept goes back almost four decades, but since conventional fibers allow light beams to travel in parallel and interact with each other, jumbling the 1s and 0s encoded in each beam, is not an easy thing to do. Scientists have recently attempted to impart twists on some of the beams so that they spiral along with the fiber while others are moving in a straight line, but that has not succeeded either. Scientist Ramachandran and his team report on the development of a 1.1kilometer-long fiber that enables multiple beams to reach their target intact for the first time. Their silica fiber is doped with other materials in areas, allowing the beams to travel at slightly different speeds and stopping them from mixing. The researchers sent as many as four concurrent beams, transmitting data at speeds of up to 1.6 trillion bits per second, through their custom fiber, using an instrument called a spatial light modulator to twist the beams. They intend to use techniques already exploited by the telecom industry to cram more data into each of those beams. Ramachandran states that the team has manufactured its fiber using conventional methods at a commercial facility.

II. ANGULAR MOMENTUM OF LIGHT

C. Orbital angular momentum

The concept takes initiated in 1909 by J. H. Poynting [1], who predicted that the spin angular momentum exhibits circularly polarized light should have an angular momentum to energy ratio of σh. He suggested that any transformation of the polarization state from the linear to circular must be accompanied by an angular momentum exchange with the optical system and the author Allen et al [2]. Who proposed to initiate discussions on orbital angular momentum in the year 1992. He discussed that the OAM was a natural property of all helically phased light beams so it could be readily generated in a standard optics lab and Laser light with a Laguerre-Gaussian amplitude distribution is found to have a well-defined orbital angular momentum.

The orbital angular momentum of light (OAM) is the portion of a light beam's angular momentum, that depends on the spatial propagation field and can be further split into an internal and an external OAM instead of polarization. The internal OAM is a distinctive type of angular momentum that can be correlated with twisted or helical wavefronts. The external OAM is the source dependent on angular momentum that can be extracted from the source position and velocity. A light beam holds a linear momentum p, so an additional angular momentum may also be allocated to it $L_c = r\ X\ p$. This external angular momentum is based on the choice of the coordinate system's origin. If one selects the origin of the beam axis and the distribution of the beam is cylindrically symmetric. The external angular momentum is a type of OAM that appears when there is a paraxial light beam called helical mode in the internal OAM. These electromagnetic field helical modes are distinguished at the beam axis by a wavefront that is formed as a helix with an optical vortex in the middle. Helical modes m , are characterized by positive or negative integer numbers. The electromagnetic waves have a property like an OAM which describes the rotational degree of freedom and rotational characteristic for energy. Using an instrument called spatial light modulator to twist the plane light wave. The helical modes of the EM field are characterized by a wavefront that is shaped as a helix structure with the optical vortex in the center which can be characterized by an integer number (positive or negative) this is also called the topological charge of the optical vortex. Light has a basic property light phase and amplitude, phase generation by using the azimuthal expression for light carrying OAM is ϕ (r, ϕ) = $exp(il\varphi)$ Where ϕ is the angular coordinate and ℓ can be any integer value, positive or negative. i = $\sqrt{-1}$ and φ is an azimuthal angle [4].

B. Spin Angular Momentum

The spin angular momentum of light (SAM) is the component of the angular momentum of a light beam that can be associated with its circular or elliptical polarization when its electric and magnetic fields rotate continuously around the beam axis during the propagation [5]. The circular polarization is left (L) or right (R) depending on the field rotation direction. When the light beam is circularly polarized, each of its photons carries a spin angular momentum of $\sigma\hbar$ where $\hbar$ is reduced and the ± sign is positive for left and negative for right circular polarization. This SAM is directed along the beam axis.

C. Total electromagnetic field Angular momentum

Electromagnetic (EM) beams do not only carry energy, the power that is Poynting flux, linear momentum), and spin angular momentum (SAM and wave polarization) but also orbital angular momentum (OAM). The total angular momentum J^{EM} can be separated into two parts

$$J^{EM} = \frac{\varepsilon_0}{2iw}\{\int E^{*}XE\, d^3\varkappa + \int \Sigma E_i^{*}([(x-x_0)])E_i\hat{e}_i\}\, d^3x$$

The first part is the spin angular momentum (SAM) s^{EM} wave polarization and the second part are the orbital angular momentum (OAM) L^{EM} in general, both linear momentum P^{EM}, and angular momentum $J^{EM} = S^{EM} + L^{EM}$ are radiated out to the far zone.

III. DIFFERENCE BETWEEN SAM AND OAM

SAM is tied to the polarization of the light beam and for single-photon its value is:$s_z = \pm(\frac{h}{2\pi})$ and OAM is tied to the special structure of the wavefront where the orbital terms are generated by the gradient of the phase, it determines the helicoidal shape of the wavefront for a single photon it assumes the value $L_z = 1(\frac{h}{2\pi})$. With l=0 for a plane wave with S || k, and l ≠ 0 for a helicoidal wavefront because S processes around k. Polarization enables only two-photon spin states, but actually, photons can exhibit multiple OAM eigenstates, allowing single photons to encode much more information.

IV. WORKING PROCEDURE FOR ORBITAL ANGULAR MOMENTUM

Simple comparisons of the behavior of spin and orbital angular momentum in different situations prove to be a fruitful way to demonstrate their properties. First, however, we need to distinguish the general structures of light emitted by a laser and also its properties when converted to, for instance, an LG beam. Laser beams usually have spherical wavefronts while the azimuthal phase leads to beams with 1 intertwined helical wavefront. The LG beam is not the only example of a helical wavefront; Bessel beams, Mathieu beams, and Ince –Gaussian beams can also carry orbital angular momentum. In all cases, the interference of these helical wavefronts with a plane wave gives rise to characteristic spiral interference fringes. The production of a pure, high-order LG mode from a laser beam was first achieved using a mode convertor based on cylindrical lenses [6]. Before the Generation of LG beams with lenses, similar beams containing the same azimuthal Phase term had also been produced using diffractive optical elements Despite the various approaches that have been developed to generate helically Phased beams, they are not a feature unique to advanced optical experiment. Interference between two plane waves yields sinusoidal fringes. Interference

Between three or more plane waves leads to points within the field cross Section of perfect destructive interference around which the phase advances or Retards by 2π. Nowhere is this more apparent than when examining the optical Speckle resulting from laser light being scattered from a rough surface, where each Black speck is a perfect phase singularity. To generate pure LG modes, the cylindrical lens mode converter remains a convenient approach.

V. TWISTED LIGHT COMMUNICATION

The principle behind the twisted-light concept was to bundle more information in a single beam of light which itself was a composite of other beams “twisted” or “corkscrewed” together. The twisted-light method proved to be promising, and in the latest development of the technology, researchers have shown that twisted light can be used in optical fibers, showing that the technology can be used practically. Twisted light can carry far more information than regular light because it can encode more data within a single beam by using twists within the light itself to carry more information. Light has two kinds of momentum, spin angular momentum and orbital angular momentum [3]. Using the latter, twisted light packs more data into the light by packaging this within the light’s varying degrees of twists. A new kind of optic fiber that can carry “twisted light” could provide internet speeds of over a terabit a second. The technology relies on donut-shaped laser light beams called optical vortices, or orbital angular momentum (OAM) beams, in which the light twists like a tornado as it moves along the beam path rather than in a straight line. Optical vortices were previously thought to be unstable in optical fiber, but Boston University (BU) Engineering Professor Siddharth Ramachandran has now designed a fiber capable of propagating them. Telecommunications companies use light to encode and send data through fiber-optic cables. Over the last few decades, scientists have increased bandwidth by enabling a single beam to carry more information, but their progress soon will be outpaced by the vast amounts of data people exchange. Laying more fibers would be expensive. The solution is to dispatch multiple beams of light through a single fiber. The idea goes back nearly four decades, but it’s not an easy thing to do because traditional fibers allow light beams moving in parallel to interfere with each other, jumbling the 1s and 0s encoded in each beam. Recently, scientists have tried imparting twists into some of the beams so that they spiral along with the fiber while others travel in a straight line, but that hasn’t worked either. Resigned to this light mixing, some researchers have created complex algorithms that decipher the amalgamated beams at the end of the cable, but the algorithms are slow and not 100 percent effective. [7] scientists report building a 1.1-kilometer-long fiber that, for the first time, allows multiple beams to reach their destination intact. Their silica fiber is doped in places with other materials, which causes the beams to move at slightly different speeds and prevent them from mixing. Using an instrument called a spatial light modulator to twist the beams, the researchers sent as many as four concurrent beams, transmitting data at speeds up to 1.6 trillion bits per second, through their custom fiber. They hope to squeeze more data into each of those beams using methods already exploited by the telecom industry. fibers were manufactured at a commercial facility using standard methods, so if they were mass-produced, the fiber should not cost much more than those now in use. The twist in the beam is imparted due to a property known as “orbital angular momentum.” A beam of light that carries digital data can twist in a helix as it moves through space. The fascinating thing is that there can be many different rates of twisting for a beam. This property allows us to combine many data-carrying beams of differently twisted light. These beams occupy the same space but can be efficiently separated at a receiver [8]. By doing so, we can increase the data capacity that is occupying the same space.

Recently, we transmitted data over open space in a lab at a rate of up to 2.5 terabits per second using multiple beams of light that were each twisted into a different helix. Each beam acted as an independent data stream – much like separate channels on your radio. To put that in layman’s terms, the broadband cable that you probably use to check your email supports up to about 30 megabits per second. Our twisted-light system transmits more than 85,000 times as much data per second.

VI. APPLICATIONS

Before long, this research, which was funded by the Defense Advanced Research Projects Agency (DARPA) as a part of the InPho (Information in a

Photon) program, will find its way into a variety of applications, both in space and on Earth. In the future, this will likely require a more cost-effective and integrated approach. At least in the near term, the technology's potential applications for terrestrial communications are limited, since it requires a clear line of sight and no turbulence or other interference. Even on a clear day, the turbulent atmosphere will distort the phase front of the light wave. It is a bad idea to rely on phase manipulations for unguided atmospheric transmissions. It may be better to be used in a vacuum. Because of atmospheric issues, therefore, the process might be more practical in satellite and space communications than on Earth, since space has no turbulence. This work can find various applications where large amounts of data must be exchanged between two points and OAM multiplexing is technically and economically advantageous. Turbulence may hurt the performance of such optical wireless links, which means that longer-range applications can succeed in space. Just as promising is the possibility that OAM processes could be adapted to fiber optic cables, which are the basis of the Internet and most other terrestrial communications.

OAM modes can play even a more important role in fiber-optic communications, where work on all forms of space-division multiplexing is currently a very hot research topic. Preliminary results on long-range OAM transmission have already been reported. There are many other potential applications of OAM data transmission, including medical imaging and even the detection of landmines.

VII. CONCLUSION

Twisted light is the next step in data communication, but tests had shown that standard optical fibers were unable to carry the twisted light beams effectively. But in the present study, the researchers used a new fiber that they had developed previously, which has a multilayered structure that does not disperse the twisted light. This new optical fiber allowed the twisted light to carry reams of data, but because of its unique design, the fiber itself does not presently have a practical use, as most optical fibers used in the world are of standard design.

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