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Perspective Methods of Transferring Information via Optical Communication Channels

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Abstract

Perspective methods of information transfer in optical communication channels based on the latest achievements of quantum physics are considered. In the near future, these methods can solve both the problem of creating an optical channel conducting with physically unlimited bandwidth, and the problem of secretly transferring information in a fiber-optic information channel. The results of the latest experiments related to the quantum properties of photons are described. The use of solitons as carriers of an information signal is considered. The technologies of using the 'temporal cloak' and noise of optical amplifiers for data transmission in fiber-optic communication lines are presented.

Keywords: optical steganography, soliton, optical fiber

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1. Introduction

At the moment, there are dozens of scientific projects that generate huge amounts of information. For them the actual problem is the transfer of data to the places of filtration, storage, further processing [1]. For example, it is expected that the global project of the near future, the SKA radio telescope, after coming to full capacity in a few years, will generate more than 1 exabyte of information per day, which is comparable to the volume of all current Internet traffic [2].

Therefore, the scientific community faces the problem of increasing the capacity of both existing communication channels and using the latest information transfer technologies, some of which are described in this article.

The article also looks at promising technologies that allow to solve the actual problem of secret information transfer in fiber-optic communication lines.

2. Transmission of Information Using a ‘Twisted’ Light

To create a channel of unlimited bandwidth, it is proposed to use the orbital angular momentum of photons with respect to the direction of their propagation as an information carrier.

The property of ‘twisting’ is characterized by the fact that it takes only integer values. A ‘twisted’ ray creates a ring-shaped figure on the screen, and a superposition of photons with opposite values of ‘twist’ ‘L’ and ‘–L’ creates a picture in the form of ‘2L’ of correct petals on the screen. This property of the beam was used in experiments by the neural network to recognize the transmitted signal. Also, light waves swirling with different periods can propagate within one beam without interfering.

The practical suitability of the twist of photons for the long-distance transmission of information was shown by the research team back in 2013. In the course of this experiment, data was transmitted using swirling light above the center of Vienna for a distance of 3 kilometers. It was shown that the turbulence of the atmosphere practically does not affect the twist of light in the optical communication channel [3]. In 2016, the same group of scientists reported the establishment of two world records. First, a record quantum number for twisted light was achieved. It was possible to ‘twist’ the light to values exceeding 10,000 with the aid of special mirrors made of aluminum disks [4]. Second, a record was set for the transmission range of the ‘twisted’ light with the possibility of recognition. The experiment was conducted between the two Canary islands of La Palma and Tenerife, located 143 km apart. A simple message was coded with green laser light with optical holography, and it was recognized when received using neural networks. Thus, a great potential was demonstrated to transmit ‘twisted’ light in optical communication channels with the possibility of unlimited information capacity of ‘twisted’ light [5].

Unfortunately, at the moment, it is impossible to use ‘twisted’ light for transmission in the fiber-optic lines, the most common channels of communication at the moment. The property of ‘swirling’ is very unstable. It is quickly lost upon propagation in the fiber due to quantum collapse in the process of reflection of the light beam from the boundaries of the waveguide. However, recent studies have shown the possibility of solving this problem in the near future. It was announced the creation of a working prototype of multiplexing technology with separation over the orbital angular momentum. As a result, it was possible to achieve a transmission speed of 1.6 Tb/s for a special fiber created for a distance of 1.1 km. Four independent data channels were created with a different twist state in one beam. A system of special lenses and optical modulators, as well as the use of a special cable with different refractive indices, made it possible to create special 'twisted' light waves that retained their stability within the optical fiber for a long time. Moreover, the created optical fiber has a variable refractive index at the cut, so that light with a flat and swirling front propagates in it at different speeds. According to the researchers, the relative simplicity of their technology and compatibility with many other components of the fiber network will speed up the Internet several times in the coming years [6].

In the near future, it is promising to use 'swirling' light for the needs of quantum cryptography. Bandwidth is the main problem for quantum key distribution systems. Standard quantum key distribution systems such as BB84 or B92 use light polarization for encoding. This limits the information capacity of one transmitted photon and directly affects the bandwidth of the communication channel. In [7], an example of the technology of quantum cryptography is given. In this example, seven values of the orbital angular momentum of the pulse (from –3 to 3) are used as one basic state, and the polarization state of the photon as the other. A lossless communication line with a length of 2 meters was presented, with the information capacity of the photon averaging 2.05 bits.

Also, in the future, it is promising to use 'twisted' light for the needs of long-distance space communications. Communication via radio channels with probes located at a considerable distance from the Earth is complicated; firstly, by the low power of the signals emanating from the space station, secondly by the dispersion of the radio wave in space, and, finally, by the Doppler shift of the frequency of the radio wave. Therefore, modern systems of long-range space communications can provide only an extremely low data transfer rate. For example, a high-resolution image transmission from Mars can take about 90 minutes [8]. Using 'twisted' laser beams instead of radio waves as a means of data transmission can give a significant gain in transmission speed. And the first step in this direction was made by NASA in 2013. Using a polarized laser beam, it was possible to transmit data at a rate of 622 MB/s from the LADEE probe, located about 200 km from the lunar surface to the receiving station in New Mexico. In the reverse direction, the transmission was carried out at a speed of about 30 MB/s. The transmission rate achieved as a result of the experiment was several times higher than the transmission by radio waves shown by space vehicles from the surface of the Moon ever before [9].

3. Optical Steganography

This term is understood as the inability of the intruder to determine the very fact of information transfer in publicly available fiber-optic communication lines at the physical level of the network. This topic is relatively new, and in the scientific literature there are only a few publications devoted to this topic.

In the vast majority of works, it is argued that the container for the transmitted message should be the noise that is present in the optical fiber. In the fiber-optic communication line, there is such noise as thermal, shot and noise ASE (Amplified spontaneous emission). ASE is the noise of amplified spontaneous emission, and it can be considered as a carrier of a latent signal. But there are other types of noise, for example, noise OBI (optical beat interference) in the optical fiber, which make it difficult to add a hidden signal [10].

Optical steganography was first theoretically presented in 2006 [11], and was first demonstrated in 2007 [12]. In works, it is the ACE noise that is used as a carrier of a hidden signal. This noise occurs in erbium optical amplifiers EDFA (Erbium Doped Fiber Amplifier) [Figure 1]. These amplifiers, due to the possibility of simultaneous amplification of signals with different wavelengths [13], are widely used in various fiber-optic communication lines, including the Internet.

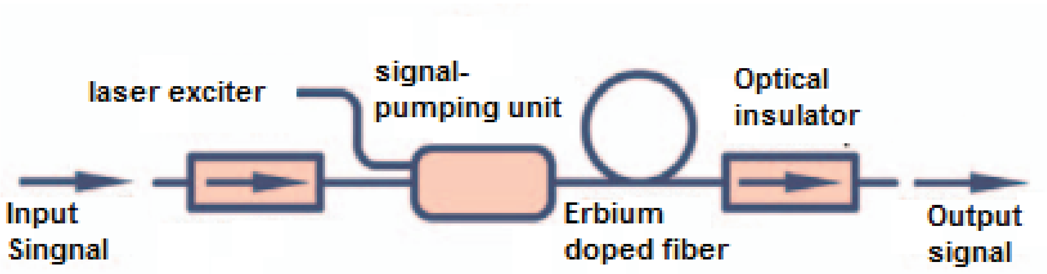

Figure 1: A simplified scheme of an erbium fiber amplifier [13].

One of the ways of steganographic information transfer is described as follows. Protection of information in it occurs on two levels. To hide the signal in the spectral domain, it corresponds to ASE noise, and to mask the signal in the time domain, a time delay and a special phase mask are used. For phase demodulation of the hidden signal, the transmitter transmits a copy of ASE noise without modulation. And after a period of time equal to the delay known to the recipient, a copy of ASE noise with a superimposed latent signal is transmitted. Moreover, since the ASE spectrum covers a wavelength range from 1520 nm to 1560 nm, the 40 nm spectrum range can support several hidden channels. With the help of this technology, it was possible to achieve a transmission speed of 500 Mb/s in an ordinary 10 Gb/s fiber-optic communication line [14].

In some works, ASE noise is suggested as a hidden signal carrier, but the latent signal is represented as a series of short optical pulses that are stretched either by optical dispersion [15] or by fiber-Bragg gratings [16].

In [17], a slightly different approach is proposed, namely, to use as an carrier an open channel represented by random data, and a hidden signal to transmit using spreading codes. The aim of the study was also to find the correlation level between the open and latent channel optical power levels and the length of the spreading code. It was shown that the optimal transmission speed in this case is about 20 Kb/sec in a network with a throughput of 5 Gb/s.

4. Solitons

An optical soliton is a short laser pulse with certain properties that has the ability to propagate in a nonlinear medium with practically no change in its main characteristics, that is, has properties that are more suitable for particles than for waves (Figure 2). It is for this reason that at the end of the last century, technologies using solitons were considered as the most promising basis for the design of modern fiber-optic communication lines [19]. Already in the early 90s, as a result of numerous experiments, significant results were obtained, which made it possible to expect that the speeds of digital soliton communication lines can be increased to 320 Gb/s per channel in the very near future, and the length of the regeneration section to 1000 km [20].

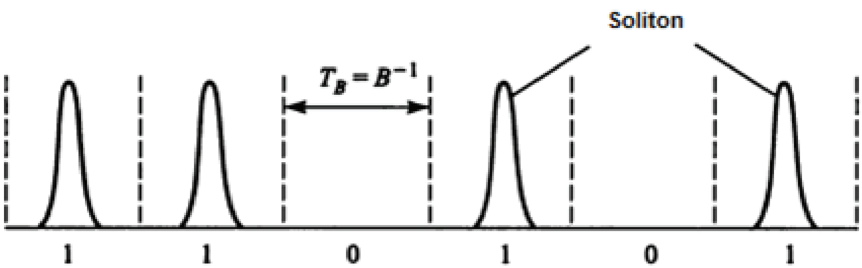

Figure 2: Sequence of solitons with binary coding of signals. Each soliton occupies a small fraction of the bit interval, which ensures the remoteness of neighboring solitons.

However, due to the development of multiplexing, that is, the possibility of organizing several channels for transmitting information using a single physical communication channel due to wavelength division, soliton technologies for transferring information using optical communication channels have temporarily become secondary

(19). Nevertheless, at present, the performance of modern communication lines is approaching its physical limit, because due to the nonlinear effects of the physical media, the transmission rate is limited to about 100 Tb/s. Such restrictions, in turn, led to a revival of interest in the topic of soliton research as a carrier of information in optical fiber, including multi-core, and other media [21].

In 2015, for the first time, it was possible to capture the processes of formation and propagation of solitons, which are formed in materials possessing magnetic properties [22]. And in 2017, the fact of transfer of information with the help of solitons in nematic liquid crystals was discovered by influencing them with magnetic fields. According to the researchers, the open magnetic-optical transmission system has the necessary flexibility for remote transmission of optical signals in any direction in real time [23].

Also in 2017, a world record was set for data transmission rates based on soliton technologies in optical fiber. As the information carrier, broadband frequency combs with different spectral lines were used, which were generated by micro resonators with silicon nitride. Two superimposed combs provided massive parallel data transfer on 179 wave channels, which allowed data transmission at a rate of 55 Tb/s over a distance of 75 kilometers [24].

5. Conclusion

In this article, the existing and the most promising methods of information transmission in optical communication channels were considered. In the near future, they can lead to the creation of an optical channel with physically unlimited bandwidth. We also examined ways to solve the problem of secret information transfer. This will enable to find a solution for the set of both cryptographic and information tasks in the near future.

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