EXPERIMENTAL STUDIES OF MULTICORE OPTICAL FIBER DURING TRANSMISSION CHARACTERISTICS OF CLASSICAL AND QUANTUM CHANNELS

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ABSTRACT

Today, it is not possible to abandon modern sources of information; with such rapid development of technology, we need to analyze large amounts of data. To a greater extent, applications that require speed and volume of transported information are responsible for the increase in transmitted data, such as streaming and cloud data processing services, as well as traffic transfer between data centers. The experimental part of the research involves several schemes for distributing a quantum channel inside a multi-core fiber, as well as different models for placing classical channels. To transmit the quantum channel, scientific and educational complexes developed by the Qrate company were used; the transmission of the quantum channel was implemented based on the BB84 protocol. The article analyzes experimental studies on the parallel transmission of three quantum channels in a multi-core optical fiber with satisfaction of the quantum bit error rate and key length, as well as a study of the influence of classical power on the transmission of a quantum channel along the adjacent core of the fiber under study. Such research provides a new direction for the development of microstructured fibers specifically for the needs of quantum communications.

KEYWORDS: *Fiber-Optic Communication Line, Bandwidth, Multi-Core Optical Fibers, Quantum Channel, Transfer Characteristics.*

1 Introduction

The transmission of information is one of the most pressing topics of the current century. Today, it is not possible to abandon modern sources of information; with such rapid development of technology, we need to draw and analyze large amounts of data in order to keep up with the times. In this regard, researchers face several global problems. First of all, let's look at the fact that the compound annual growth rate for backbone communication networks continues to grow and today is about 26% per year.

To a greater extent, applications that require speed and volume of transported information are involved in the increase in transmitted data, these are streaming broadcasts and cloud data processing services, as well as the transfer of traffic between data processing centers itself [1]. Even the most modern wavelength division multiplexing (xWDM) systems cannot cope with such an increase. In addition, based on the research carried out, it can be stated that fiber-optic transmission systems (FOTS) with single-mode fibers according to the G.652.D specification are reaching their limit.

Naturally, there are quite a lot of conditions that affect the throughput of a communication line. For example, consider a fiber-optic communication line over a regional distance of 600 km with a length of regeneration sections of 75 km. With such parameters, one optical fiber using the O-band can transmit data at speeds of up to 40 Tbit/s, and the throughput of the C-band reaches 20 Tbit/s over a similar fiber [1]. This raises the problem of increasing throughput. We will return to its possible solution a little later. Now, regarding the second issue, the last one is that the transmitted information needs to be somehow protected from intruders. It's no secret that software encryption, which is now used in 99.9% of cases, is not a 100% reliable and guaranteed method of secure data transfer. Of course, it is possible to resort to the method of encrypting data using a one-time pad, but what to do if there is so much data that this method is no longer relevant. There is such a solution – we will have to turn to elementary particle physics and resort to quantum key distribution.

To implement a quantum key distribution system, it is necessary to use two optical fibers, one of which will transmit the key (quantum channel), and the other will transmit encrypted information (classical channel). And now we are again faced with the problem that we do not have enough fibers in the cable for data transmission, and in addition we need to allocate a second fiber for transmitting the key, the speed of which is only 30 kbit/s, it turns out, in order to increase the number of subscribers or bandwidth quantum channel, more than one fiber may be required [2]. Once we have outlined the tasks, we can move on to a review of technologies and experiments that can improve the future prospects for the development of modern communications.

2 SDM technology and optical fiber

To solve two such difficult problems, the modern technology of spatial multiplexing SDM (Space Division Multiplexing) of optical fiber - multi-core fibers (MCF) - comes to the rescue. This development makes it possible to transmit several streams of information over one optical fiber, the diameter of which is slightly larger than that of single-mode optical fibers, the latter being 200-250 microns. It is possible to place up to 40 optical fiber cores under a common cladding [3,4,5], without much influence on adjacent channels. Today, a very limited number of optical cores is often used, since this is due to the influence of crosstalk on signal transmission along adjacent spatial channels.

When carrying out experimental studies, a seven-core hexagonal optical fiber was used, developed by the scientific center of the Scientific Center for Vocations of the Russian Academy of Sciences [6]. To transition from multi-core to single-core technology, a special FAN-IN/FAN-OUT device was used [7], which provides such a conversion. The optical fiber bonded to the I/O device has the characteristics presented in Table 1.

Table 1. Transfer characteristics of multi-core fiber

Channel no.		1st gluing		2nd gluing	
	$\sum \alpha$, dB	α, dB	β, dB	α, dB	β, dB
1	0,5	0,4	-47	0,1	-56
2	1,2	0,55	-52	0,65	-55
3	1,7	0,6	-47	1,1	-60
4	1,7	0,6	-47	1,1	-57
5	1,2	0,1	-44	1,1	-65
6	1,6	0,5	-50	1,1	-63
7	1,3	0,45	-63	0,85	-55

Where $\sum \alpha$ – total losses; α – losses; β – reflection.

From the presented data we can conclude that during a double transition between fibers of different types, there are significant power losses. The maximum total loss is equivalent to the attenuation of eight kilometers of a typical single-core fiber. In addition, additional optical reflections appear at the transition junctions, which can negatively affect the transmission of the useful signal.

A cross section of the multicore fiber used in the experiment is illustrated in Figure 1.

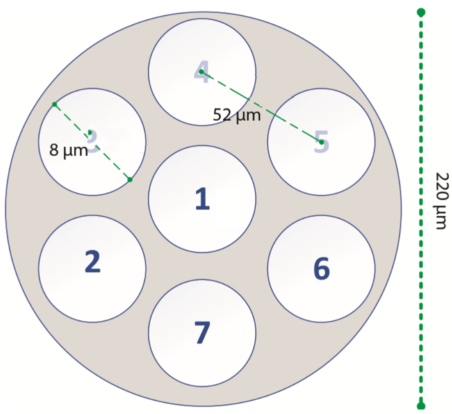

Fig. 1: Cross section of a 7-core hexagonal optical fiber

Scientific and educational complexes developed by the Russian company QRate were used to transmit the quantum channel. The operation diagram of this equipment is shown in Figure 2 [8].

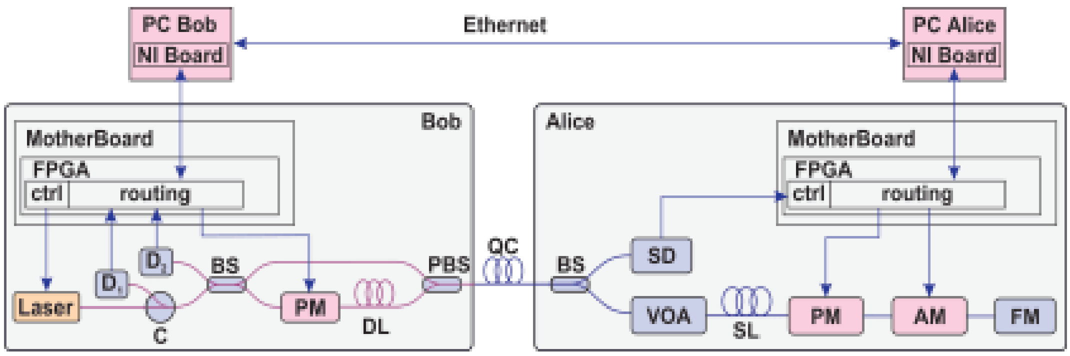

Fig. 2: Scheme of the QRate scientific operation and educational complex [8]

Quantum channel transmission is implemented based on the BB84 protocol [9], the first protocol that was proposed in 1984 by Charles Bennett and Gilles Brassard.

A research stand has been assembled at the Moscow Technical University of Communications and Informatics (MTUCI). The multi-core optical fiber is laid in an optical cassette in a cross-connect; optical pigtails with FC/UPC and FC/APC outputs are welded to the unterminated outputs of single-mode fibers using a Fujikura CT-101 cleaver and a Fujikura FSM-100P+ splicer. Various degrees of polishing were used due to the fact that the connection interface of the quantum installation has an FC/UPC form factor, and the laser connector is compatible with FC/APC connectors, this made it possible to minimize losses on the adapters. To quickly change channels, SC type connectors are provided at the outputs; the latter operate using push-pull technology. The complete assembly of the stand is shown in Figure 3.

Fig. 3: Multi-core fiber research bench

The experimental part of the research involves several schemes for the distribution of a quantum channel inside a multi-core fiber, as well as different models for placing classical channels, which are shown in Figure 4.

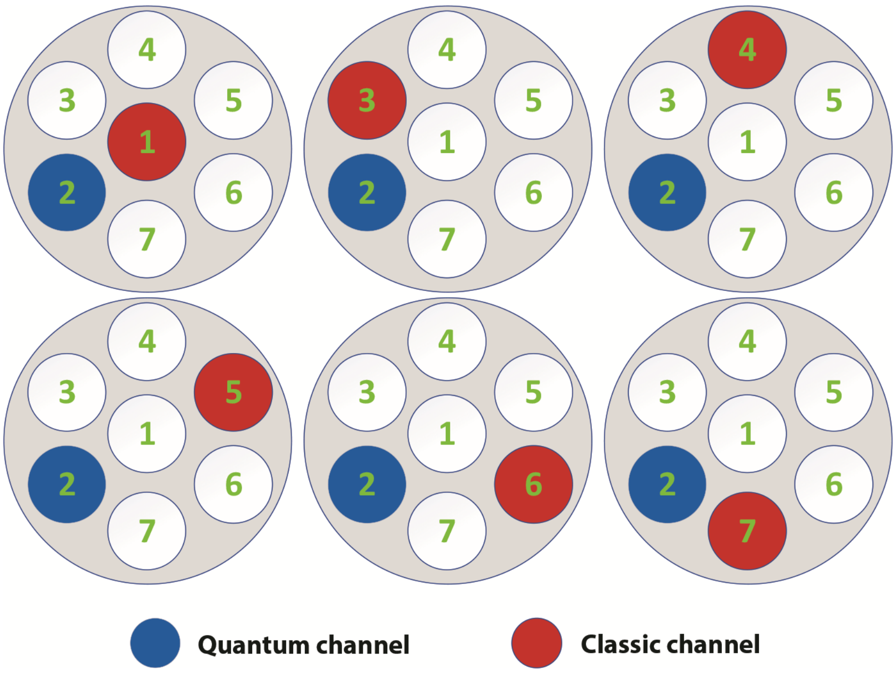

Fig. 4: Connection options for classical and quantum channels -

Based on the data obtained as a experiment result, following histograms were generated, presented in Figure 5.

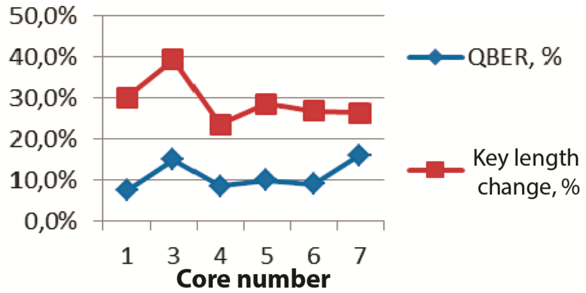

Fig. 5: Dependence of QBER on key length

From the graphs above, you can see that the key length changes in direct proportion to the change in the quantum bit error rate (QBER). It is also worth noting that transmission of a classical channel in nearby cores (in the 3rd and 7th, when transmitting a quantum channel in the 2nd core) with a power of 1 mW greatly affects the QBER and, as a consequence, the key length too. Along with this, to ensure the security of transmission of a quantum key over an optical fiber, it is necessary to ensure QBER<11%. Exceeding this value means problems in the channel or the latter is compromised, in which case the key is destroyed. To ensure the transmission of guaranteed protected quantum states of the photon, it is necessary to use the first core to transmit the classical channel or reduce its radiation power.

Figure 6 shows histograms of the transfer characteristics of a multi-core optical fiber, with a fiber length of three meters.

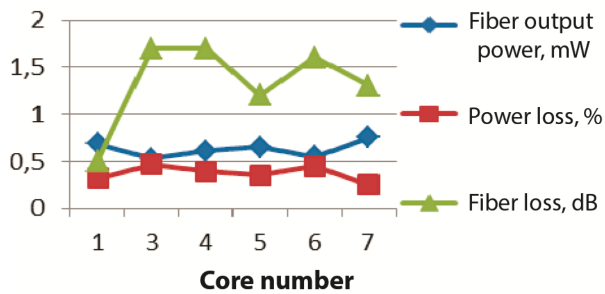

Fig. 6: Optical fiber transmission characteristics

In addition to the experiments described above, research has been carried out on the transmission of several classical channels with a total power of 1 mW. Schemes for connecting the laser are shown in Figure 7.

In the first case, data were taken with the transmission of four classical channels with a power of 0.25 mW per channel, and in the second case, values were obtained with the transmission of two classical channels of 0.5 mW per channel.

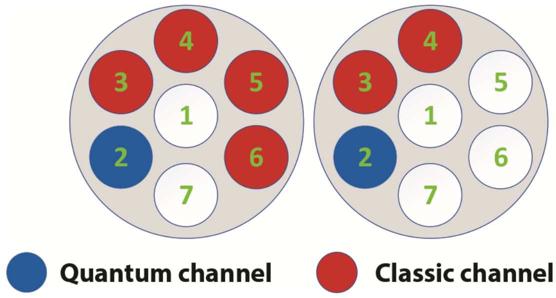

Fig. 7: Optical fiber transmission characteristics

Based on the results of this experiment, a comparative analysis was carried out on the transmission of total power (1 mW) through four and two channels. Figure 8 shows the results of the influence of four classical channels on the second quantum one.

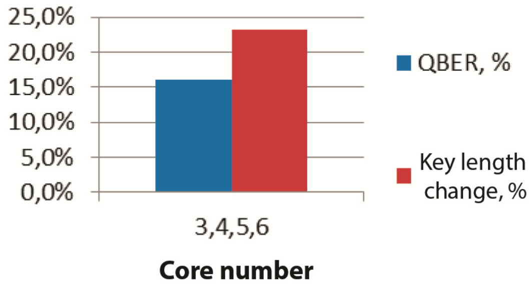

Fig. 8: Influence of four classical channels on the second quantum

It makes much more sense to place a classical channel, one core apart from a quantum channel, or at the center of a multi-core optical fiber, rather than splitting the power across four or two cores. Apart from the use of additional cores in this option, the latter also has no advantages for a reasoned choice. Figure 9 shows two diagrams for connecting three quantum channels.

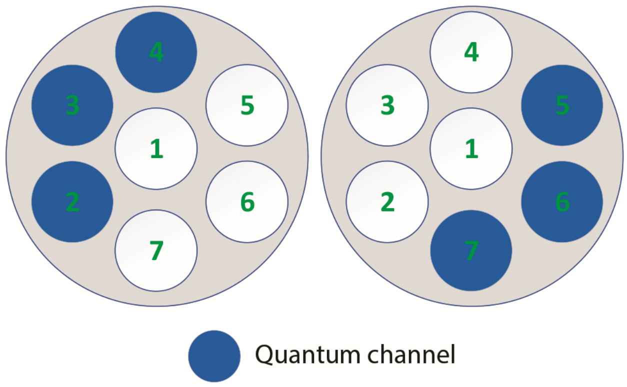

Fig. 9: Connection diagrams for three quantum channels

Along with the above-described research, a parallel launch of three quantum channels via multi-core optical fiber was carried out at two scientific and educational complexes and one industrial installation from the QRate company with a line length of the latter of 18 km. Two options for placing quantum channels on the cores were tested: 2,3,4 and 5,6,7. Since in this design of a multi-core optical fiber, quantum channels do not affect neighboring cores, according to the results of the experiment, the fluctuations in parameters were: QBER in the range of 1.5-2% and key lengths from 1900 to 2100 characters, which is associated with different attenuation and reflection on different cores.

3 Conclusion

The work shows and explores several options for implementing quantum-protected communication. Since new technologies require new solutions, therefore, based on theoretical arguments, multi-core fiber was chosen for experiments. In the experimental part, it was proven that in addition to the widespread use of microstructured fibers in various sensors and compaction of classical communication channels, the latter also find their application in quantum key distribution. Such research provides a new direction for the development of MCB fibers specifically for the needs of quantum communications. The general conclusion, which was formulated after conducting a large number of diverse experimental studies, gives us an understanding that when using microstructured fiber technologies in modern communication systems, quantum channels will predominate in the fibers, and classical signals will have to be more compressed. This ratio will eliminate unnecessary light on quantum channels and simplify the correct transmission of photons.

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