UDC 621. 391

# THE METHODOLOGY OF INFORMATION CAPABILITIES ESTIMATION FOR FIBER-OPTICS COMMUNICATION

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The method for assessing a channel capacity and productivity of fiber-optic communication line (FOCL) based on the DWDM (Dense Wavelength Division Multiplexing) technology is proposed. The interrelation between noise-immunity factors and information characteristics of FOCL is highlighted.

## Introduction

The growing needs of the Internet and its users, the success of IP-telephony and the increased speed of information processing led to the fact that ordinary twisted pairs – wires to transmit information used in the last century – no longer meet the usual requirements, and thus the fiber-optics communications are widely promoted in the world.

Today, the number of fiber-optics communication links are measured in tens of thousands laid kilometers per a year. Almost all major companies not only support the technology, but also conduct their research. Dense Wavelength Division Multiplexing (DWDM) technology is one of the most interesting technologies – superdense wavelength division multiplexing, and allows you to speed up significantly the information flow on major highways.

FOCL bandwidth is terabits per a second, and any other system cannot produce such high data transmission speed.

## Problem statement

The signal to noise ratio is a base for determination the bandwidth of channel capacity, but this factor is not used in explicit form for design and utilization of FOCL.

Instead of use the signal to noise ratio for determination a noise-immunity, the bit error rate (BER) can be used. BER is the ratio of incorrectly decoded bits $Ne$ to the total number of transmitted bits $N$ [1]: BER $=Ne/N$.

The research of FOCL information capabilities is an urgent task from the position of classic noise-immunity indicators, because exactly the estimation with classic noise-immunity indicators is more complete and accurate.

The most interesting task is an assessment of channel capacity and productivity of DWDM – the leading technology for signals transmission via FOCL.

## The methodology of information capabilities for FOCL

As opposed to traditional technologies, when one signal stream is transmitted over one optical fiber, the DWDM technology is able to organize a plurality of separate SDH signal streams over a single optical fiber at the expense of spectral or optical multiplexing.

The general algorithm of the proposed method in the article is the definition of the following characteristics (Fig. 1).

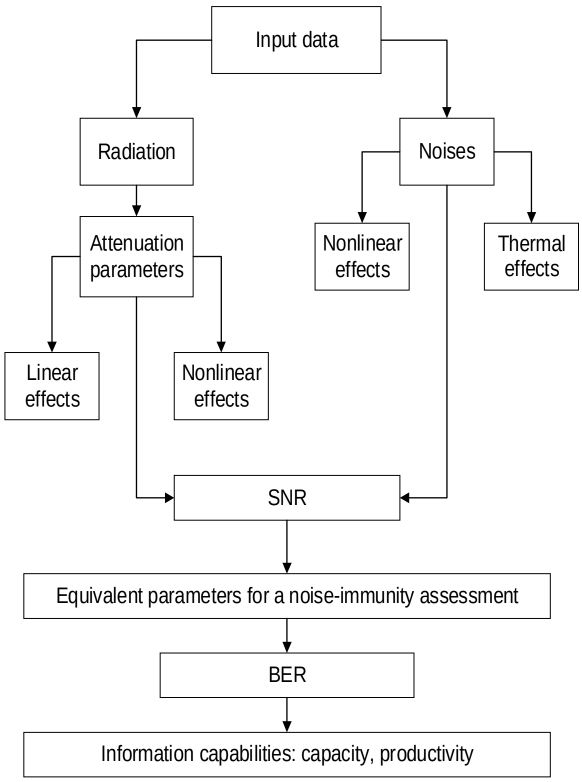


Fig.1. The calculation methodology of the FOCL information capabilities

The main component of the DWDM system is an optical fiber. Various nonlinear effects are created in the optical signal transmission medium in conjunction with other features of DWDM technology, what leads to optical crosstalk between the channels with decreasing the power of the transmitted signal. This leads to BER increasing in FOCL, and, as a consequence, to the transmission quality decreasing in DWDM. The highly urgent problem is a construction of mathematical model for nonlinear effects influence on quality factors and information possibilities of fiber-optics systems.

Research results that are related to the FOCL power indicators are presented in [2].

The Forward Error Correction (FEC) is applied in order to improve the quality of data transmission over FOCL using the technology DWDM. Using of FEC is indeed the use of error-correcting (correction) coding. Some special coding methods are developed for this purpose. The Reed-Solomon (RS) code is taken as an example for analysis the effects from using different FEC codes on fiber-optics telecommunications systems quality indices and information capabilities.

The FOCL capacity evaluation for DWDM technology can be matched to Shannon axiomatics in the bounds of discrete signal transmission model:

$$C_{DWDM} = V_C \cdot \begin{bmatrix} 1+(1-p_S)\cdot \log_2(1-p_S)+ \\ +p_S \cdot \log_2 p_S \end{bmatrix} \quad (1)$$

where $Vc$ – digital data transmission speed in a FOCL; $ps$ – the symbol error probability.

The binary amplitude shift keying (BASK) with the encoding method named non-return to zero (NRZ) is used in a system. It allows to reach the data transmission speed 10 Gbps over a single optical channel.

The amplitude shift keying (ASK) is the most common format at the present time. The direct modulation is possible in the transmitter based on either light-emitting diodes or any type of semiconductor lasers [3].

The pumping current is modulated in transmitters with direct modulation (Fig. 2) in accordance with the information sequence *m(k)*. The output power of the laser light is modulated under the influence of modulated pumping current. This method of implementation the amplitude format is a dominant format in relatively low-speed transmission systems (less than 2.5 Gbps), especially in metropolitan and access networks.

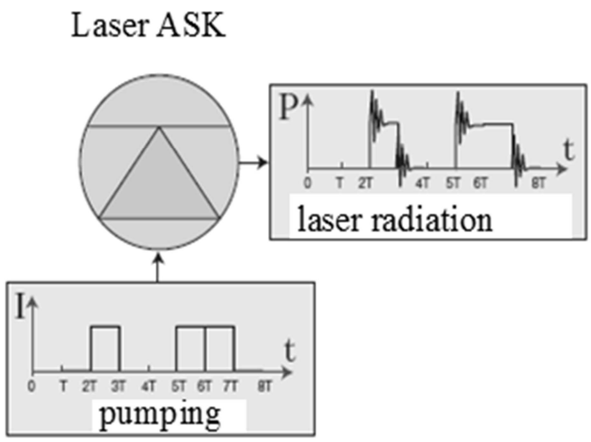


Fig. 2. Modulated laser radiation with direct modulation.

Information sequence *m(k)*: 00100110, $T = 1/B$ .

Productivity is determined in concordance with the expression (2):

$$R_{DWDM} = V_S \cdot (1+(1-p_b)\cdot \log_2(1-p_b) + p_b \cdot \log_2(p_b)), \quad (2)$$

where $Vs$ – data transmission rate from the source; $p_b$ – BER of information.

The most complex task is to determine the errors probability as a function of Q-factor – quality index of FOCL:

$$BER_{noFEC} = \frac{1}{Q\sqrt{2\pi}} \cdot e^{\frac{-Q^2}{2}}. \quad (3)$$

The Q-factor value is proposed to be defined in accordance with the relationship:

$$Q = \frac{2\cdot OSNR \cdot \sqrt{\frac{B_0}{B_e}}}{1+\sqrt{(1+4\cdot OSNR)}}, \quad (4)$$

where $Be$ – the bandwidth of photodetector’s electrical filter, MHz; $B_0$ – the optical signal band spectrum, MHz.

The OSNR is the signal to noise ratio at the receiver side and it is determined by the ratio of signal power and noise power:

$$OSNR = \frac{P_S}{P_N} \quad (5)$$

Let’s consider the DWDM system as an example (Fig. 3). The main elements of the system are the DWDM multiplexer and demultiplexer, FEC encoders and decoders. Channels from the Synchronous Digital Hierarchy (SDH) are selected as information sources.

These channels are called as STM-64 (Synchronous Transport Module) with transmission rates 10 Gbps.

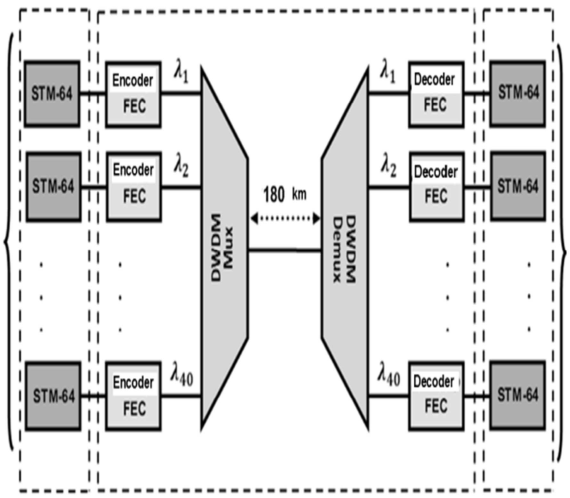


Fig.3. The simplified diagram of DWDM systems.

The FEC encoder is included into the transmission part of each optical path. The digital stream STM-64 feeds to the FEC encoder. The calculated redundant bits are added to a stream in the FEC encoder and help perform a coding procedure. The digital stream with higher transmission rate is formed at the output of FEC encoder. The FEC decoder is included into optical path on the receiver side. FEC decoder detects and corrects errors in a digital stream after transmission over an optical path, removes a redundancy that entered by the FEC encoder and restores the received bits stream.

## Reed-Solomon codes

One of the most popular FEC codes is the RS code. RS code is a very effective and simple for realization *(k, n)* block code to detect and correct errors in bytes. The input word for it is a block of *k* bytes and the output word is a codeword of *n* bytes that includes the *k* source bytes and *(n-k)* check bytes. RS code guarantees $t = \frac{(n-k)}{2}$ bytes will be detected and corrected, and the position of error bytes in the code word is absolutely unimportant. The parameter t is called "error-correcting capability of the code". The code rate is determined by the expression $R = \frac{k}{n}$, and it characterizes the code redundancy $Q_{EXC} = (1-R)\cdot 100\%$ that is caused by encoding [4].

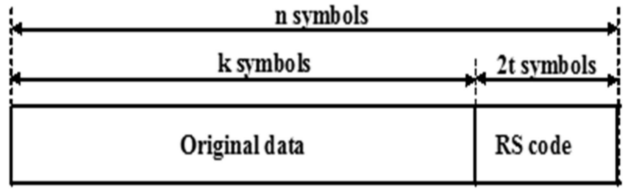


Fig. 4. The data block on the RS encoder (n, k).

Let's consider and analyze the effect of RS codes to the BER and symbol error rates (SER) as a function of data transmission channel energy parameter – Q-factor (Table 1, Fig. 5).

Let's compare the probability of bit error in a system with FEC coding and in a system without FEC coding.

$$BER_{FEC} = \frac{2^{m-1}\left[\sum_{i=1+t}^{n}\left[\left(\frac{i+t}{n}\right)\cdot\left[\frac{n!}{(n-1)!i!}\right]\cdot(BER)^{i}\cdot(1-BER)^{n-i}\right]\right]}{2^{m}-1}. \quad (6)$$

Table 1. BER values for different energy budgets and RS code types.

| | BER no FEC | BER with FEC | | | | | |
|---|---|---|---|---|---|---|---|
| Q, db | | RS (31,25) | RS (31,29) | RS (63,51) | RS (63,59) | RS (127,103) | RS (127,125) |
| Code rate | | 0.81 | 0.935 | 0.81 | 0.936 | 0.81 | 0.9685 |
| 1 | 0.159 | 0.1504 | 0.106 | 0.176 | 9.26·10-2 | 0.1219 | 8.58·10-2 |
| 2 | 0.023 | 9.951·10-3 | 1.37·10-2 | 3.65·10-3 | 1.487·10-2 | 6.68·10-3 | 1.5·10-2 |
| 3 | 1.35·10-3 | 1.139·10-5 | 1.4·10-4 | 1.42·10-8 | 1.5·10-4 | 2332·10-9 | 2.12·10-4 |
| 4 | 3.67·10-5 | 5.63·10-10 | 1.93·10-7 | 7.197·10-17 | 1.36·10-7 | 1.125·10-19 | 1.62·10-7 |
| 5 | 2.867·10-7 | 2.13·10-15 | 4.9·10-11 | 2.17·10-27 | 1.97·10-11 | 9.62·10-33 | 1.76·10-11 |
| 6 | 9.86·10-10 | 6.68·10-22 | 2.3·10-15 | 5.35·10-40 | 4.63·10-16 | 1.847·10-48 | 2.943·10-16 |

Fig. 5 demonstrates a greater code correction dominance capability in determining the BER.

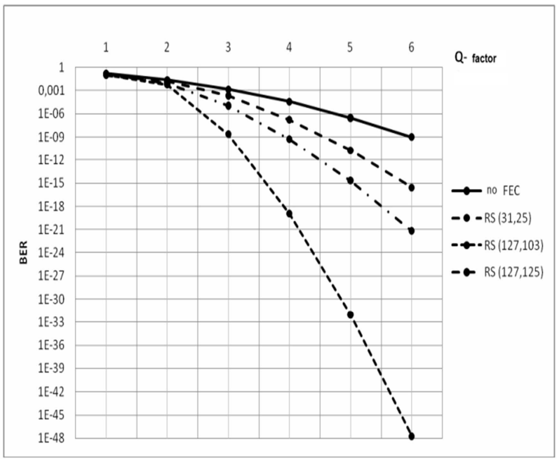


Fig. 5. BER as a dependency from a communication line power budget with different RS code types.

The DWDM system channel capacity and system performance can be found if BER and data transfer rate are known.

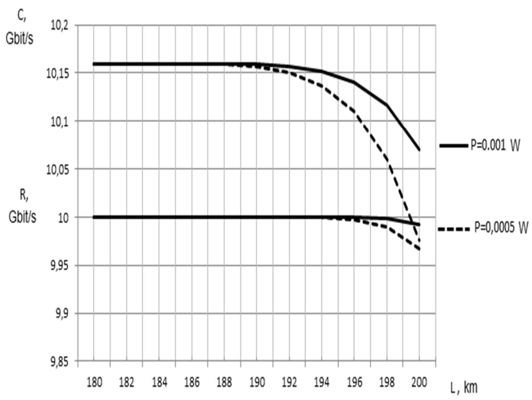


Fig. 6. The data transmission and productivity as a function of the fiber-optics line length.

The data transmission and productivity behavior are shown on Fig.6 as a function of the FOCL length for various power values at the fiber line input.

The data transmission and productivity on Fig. 6 are not constantly increasing or decreasing function. This is due to the fact that with input power increasing, the nonlinear effects and noises power appear more actively. As a result, the SNR change is unexpressed.

## Conclusions

Thus, the methodology for estimation an information possibility of systems with DWDM technology is synthesized based on high-speed, probabilistic, noise indices, nonlinear effects and characteristics of the transmission medium.

The problem of translation the fiber-optics communication line parameters to variables is solved for the first time that helps estimate a fiber-optics communication line capacity.

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Received in final form February 15, 2014