Method of objective assessment of the quality of digital TV image transmitted over NGN network using GPON access technology

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Abstract. One of the most prospective technologies and one of the ways of data transmission are determined. The parameters of optical loss resource in the network are given. The influence of optical power in the line on quality of digital television image during transmission in NGN telecommunications network using GPON access technology is considered. Equipment NetUP IPTV Combine, Optical Line Terminal, Optical Network Terminal, optical switch, optical attenuator were used as the head station During the experiment. Step dependence of the image quality on optical power in the channel is revealed. Image quality was evaluated by subjective and objective method of evaluation. The least squares method, method of equation of straight line passing through two points were used. There are several figures attached to the text for the purpose of results explanation. Recommendations of the International Telecommunication Union were used in the calculations.

1. Introduction
One of the most developed and actively implemented modern solutions of subscriber broadband access to telecommunication networks is use of PON (Passive Optical Network) technology by laying a fiber-optic cable. Taking into account strategic advantage of the optical network, it will become economically feasible to have optical access to each subscriber's apartment, i.e. FTTH (Fiber to-the-Home) technology in the near future. In this case, it is possible to use any data transfer methods: SDH, ATM, Ethernet. However, preference is mainly given to Ethernet protocols [1, 2]. In currently deployed PON networks, downstream flow from Central node to subscribers goes at wavelength 1490 nm and has speed 622 Mbit/s using ATM Protocol, supporting QoS (Quality of Service) function. Upward data flows from subscribers go at wavelength 1310 nm using Protocol of multiple access with time division TDMA (Time Division Multiple Access) and have total speed from 155 to 622 Mbit/s. In some cases downward channel at wavelength 1555 nm is used for video transmission. Thus, WDM (Wavelength Division Multiplexing) technology is used in optical subscriber access networks [3, 4]. GPON (Gigabit PON) provides a scalable frame structure at transfer rates from 622 Mbit/s to 2.5 Gbit/s, and allows systems with the same rate of forward and reverse flow in PON tree, and with the various ones. GPON is based on ITU-t standard, G. 704.1 GFP (Generic Framing Protocol), providing encapsulation in synchronous transport Protocol of any type of service, including TDM. Services based on GPON have a wide range of applications in terms of functionality and consumer characteristics. This technology is stable and promising, user-friendly [4, 5].
2. Experimental studies using GPON access technology

Nowadays GPON access technology is not only the most promising, but also the only cable environment for high-quality transmission of various signals. However, there are also problems adversely affecting the quality of digital images during operation of such networks. Purpose of this experiment was to reveal the dependence of digital image quality on optical power in the channel.

2.1. Optical loss resource

Loss resource requirement for PON network, based on Recommendation of ITU G. 983.4, is 22 dB of total loss resources for Class B PON network and 27 dB for Class C PON network. Class B and Class C PON networks are distinguished by the used laser and, indirectly, quality of optical components. Such resource loss is quite tough, especially in case of use in the design of splitters with large number of ports. Splitters in PON network cause internal losses because input power is divided between several outputs. Splitter loss depends on branch ratio and is about 3 dB per 1×2 splitter, increasing by 3 dB each time the number of outputs is doubled. 1×32 splitter has splitter loss of at least 15 dB. Loss of optical power in the channel, in practice, can cause poor quality of optical patch cord and application of number of optical splitters greater than the norm, cable aging, increasing the number of plexus, failure of terminal or station equipment.

2.2. Experimentation

Network configuration: NetUP IPTV Combine (Figure 1) – optical switch – GPON OLT (Optical Line Terminal) – GPON ONT (Optical Network Terminal). Laser class B+.

![Figure 1. NetUP IPTV Combine.](image)

Value of optical power in the line was: -27 dBm, using optical attenuator (Figure 2), signal attenuation was introduced to the limit: -32 dBm (step: -1 dB), in which there were changes in the quality of digital TV images.

![Figure 2. Optical attenuator.](image)

Image quality was controlled at the output of the head end (Figure 4) and at the output of the subscriber line (Figure 4) [6].
3. Subjective assessment of digital television image quality
First stage of analysis of the experimental data is calculation of an average assessment $Q_{HDi}$ and confidence interval for each of the demonstration, according to recommendation ITU – R BT. 500-13 (Table 1) [7].

| Number of a sequence | $Q_{HDi}$ | $Q_{HDImax}$ | $Q_{HDImin}$ | $d$ |
|----------------------|-----------|--------------|--------------|-----|
| 1                    | 4.8       | 5            | 4.6          | -27 |
| 2                    | 4.6       | 4.9          | 4.3          | -29 |
| 3                    | 4.8       | 5            | 4.6          | -31 |
| 4                    | 1.1       | 1.3          | 0.9          | -32 |
| 5                    | 1.4       | 1.75         | 1.05         | -33 |
| 6                    | 1.1       | 1.3          | 0.9          | -35 |

Parameter $d$ – value of optical power in the line, $Q_{HDi}$ – number of average values, $Q_{HDImax}$ – number of maximum values, $Q_{HDImin}$ – number of minimum values. Based on the data (table 1, let's construct a graphical dependence of digital TV image quality assessment on the optical power in the line (Figure 5).
To choose constructing method of necessary functional dependence, which can be used to objective assessment of quality of digital television images, it is necessary to determine law of statistical function of estimates distribution.

3.1. Definition of the law of statistical function of estimates distribution

To find out whether estimates distribution in case of test demonstration is normal or not, use test $\beta_2$ (calculation of function kurtosis coefficient, i.e. ratio of the fourth order moment to square of the second order moment). If $\beta_2$ is between 2 and 4, distribution can be considered as normal. This procedure is recommended in case of application of DSIS method, and DSCQS method and alternative methods [8]. Mean value of $Q_{HDi}$, standard deviation $S_{jkr}$ and kurtosis coefficient $\beta_2$ are calculated for each test demonstration, where $\beta_2$ is given by the expression [8]:

$$\beta_{2,jkr} = \frac{m_4}{(m_2)^2},$$

(1)

where $m_i$ is defined by the following formula:

$$m_i = \frac{\sum \limits_{r=1}^{N} (Q_{HDjkr} - Q_{HDi})^x}{N}.$$  \hspace{1cm} (2)

Moment of the fourth order $m_4$ is 0.0832 in accordance with the expression (1), moment of the second order $m_2$ is 0.16 in accordance with the expression (1) for the first test sequence (table 1). Function coefficient of kurtosis $\beta_2$ was equal to 3.25 in accordance with the expression (2). Since the condition $2<\beta_2<4$ is satisfied, distribution for the first test sequence can be considered as normal [9, 10]. Condition $2<\beta_2<4$ is also satisfied for the remaining test sequences.

4. Subjective assessment of digital television image quality

Based on the obtained dependence of the subjective assessment of digital television image quality (Figure 6), it can be seen that dependence of $Q_{HDi}(d)$ is close to functional dependence close to the step function. Let's define mathematical model of the signal using dynamic representation [8], namely using Heaviside function [9–13]. Let's denote the areas (Figure 6).

![Figure 6. To explanation of signal model calculation.](image)

Mathematical model of the signal (figure 6) is given by the system of equality:
Let's express $Q_1$ and $Q_3$ through multiple regression equations. The least squares method is used to estimate the parameters of the multiple regression equation.

4.1. Estimation of regression equation for $Q_1$ and $Q_3$

Let's define vector of regression coefficients estimates. According to the least squares method, vector $s$ is obtained from the expression:

$$s = \left( X^T X \right)^{-1} X^T Y .$$

Regression equation for area $Q_1$:

$$Q_1 = 4.73 + 0d .$$

Regression equation for area $Q_3$:

$$Q_3 = 1.91 + 0.0214d .$$

4.2. Estimation of equation for $Q_2$

Estimation of equation for $Q_2$ is calculated using equation of straight line passing through two points, using the expression:

$$\frac{Q_2 - Q_1}{Q_3 - Q_1} = \frac{d - d_1}{d_2 - d_1} ,$$

Where:

$$Q_2 = -0.214d^2 + 2.16d + 92.15 .$$

4.3. Mathematical expression for objective assessment of digital TV images quality

Let's determine values of Heaviside function for $Q_1$, $Q_2$, $Q_3$.

For $Q_1$:

$$h(d - 27) = \begin{cases} 1, & d \geq 27 \\ 0, & d < 27 \end{cases}$$

For $Q_2$:

$$h(d - 31) = \begin{cases} 1, & 31 \leq d \leq 32 \\ 0, & d < 31 \end{cases}$$

For $Q_3$:

$$h(d - 32) = \begin{cases} 1, & d \geq 32 \\ 0, & d < 32 \end{cases}$$

Let's make mathematical expression for objective assessment of digital TV images quality:

$$Q_{HDob}(d) = Q_1 h(d - 27) + (Q_2 - Q_1) h(d - 31) + (Q_3 - Q_2) h(d - 32)$$
Let's make a table of number of subjective and objective assessments of digital television image quality (Table 2).

**Table 2.** Calculated average values of the estimates taking into account confidence intervals.

| d   | Subjective $Q_{HDi}$ | Objective $Q_{HDi\,ob}$ |
|-----|---------------------|-------------------------|
| -27 | 4.8                 | 4.73                    |
| -29 | 4.6                 | 4.73                    |
| -31 | 4.8                 | 4.73                    |
| -32 | 1.4                 | 1.27                    |
| -33 | 1.1                 | 1.25                    |
| -35 | 1.4                 | 1.21                    |

![Figure 7](image.jpg)  
Figure 7. Graphic dependence of number of subjective and objective assessments of digital image quality on value of optical power in the line.

**5. Conclusion**

Study of GPON access technology revealed that change in optical power in the channel leads to distortions in digital TV image.

Studying dependence of digital TV image quality on optical power in channel, step dependence within the range from –31 to –32 dB is determined.

The law of statistical distribution in the subjective assessment of image quality is determined.

Mathematical model of objective assessment of quality of digital TV image was offered on the basis of system of equality of Heaviside function, corresponding to subjective assessment of image quality according to recommendation of ITU-R BT.500-13.

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