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RESEARCH ARTICLE

Assessment reliability parameters of the DVB-T2 broadcasting station's equipment with local content insertion

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Abstract. Local content modification provided to subscribers of the terrestrial digital television signal is necessary to provide the technical possibility of organizing inserts of local content signals, such as TV programs of regional broadcasters, as well as information on emergency situations. Broadcast multiplexes of federal TV programs are designed for use within the corresponding time zone (A, B, C, D, M). In each time zone, there are a number of regions, in each of which there are local TV and radio companies that produce local content that must be delivered to the subscribers of the whole subject. The task of embedding/modifying content at each remote transmitting station is performed by an inserter or local content insertion device (ETSI TS 102773). The reliability parameters of the restorable system for organizing terrestrial television broadcasting at a remote station with the content modification were calculated in this article. Tables and a graph of the broadcasting system states are presented, on the basis of which, systems of Kolmogorov differential equations are compiled. It was found that additional redundancy organized by connecting the output stream from the RX1 receiver directly to the transmitting device allows for a 2.5-fold increase in the average operating time between failures, as well as an increase in the availability factor by 5.26 percent. All calculations were performed using the *SimInTech* software package. The influence of automatic redundancy of the local content inserter and the transmitter on the occurrence of errors in the stream that affect the quality of the output signal is considered. The relationship between the availability factor and the components of the Quality of Service parameter – SAE, SDE, and SIE is determined.

Keywords: local content insertion, T2-MI stream, multiplex, Quality of Service, terrestrial television broadcasting, redundancy, reliability

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НАУЧНАЯ СТАТЬЯ

Оценка параметров надежности комплекса оборудования станции эфирного телевещания DVB-T2 с регионализацией контента

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Резюме. Модификация контента, предоставляемого абонентам эфирного цифрового телевизионного сигнала, необходима для обеспечения технической возможности организации врезок сигналов местного наполнения, таких как телепрограммы региональных вещателей или информация территориальных органов ГО ЧС. Вещательные мультиплексы федеральных телепрограмм рассчитаны на использование в рамках соответствующей временной зоны (А, Б, В, Г, М). В каждой временной зоне находится целый ряд регионов, в каждом из которых существуют местные телерадиокомпании, выпускающие контент локального характера, который необходимо доставить до абонентов целого субъекта. Задачу врезки/модификации контента на каждой удаленной передающей станции выполняет инсертер или устройство вставки локального контента (ETSI TS 102773). В статье проведен расчет параметров надежности восстанавливаемой системы организации эфирного телевещания на удаленной станции с учетом модификации контента. Представлены таблицы и граф состояний системы вещания, на основании которых составлены системы дифференциальных уравнений А.Н. Колмогорова. Установлено, что дополнительное резервирование, организованное путем подключения выходного потока с приемника RX1 непосредственно на передающее устройство, позволяет в 2.5 раза повысить среднее время наработки между отказами, а также повысить значение коэффициента готовности на 5.26%. Все расчеты выполнены с использованием программного комплекса *SimInTech*. Рассмотрено влияние автоматического резервирования оборудования врезки контента и передатчика на возникновение ошибок в потоке, влияющих на качество выходного сигнала. Определена взаимосвязь коэффициента готовности и составляющих параметра Quality of Service – SAE, SDE и SIE.

Ключевые слова: регионализация контента, T2-MI поток, мультиплекс, Quality of Service, эфирное телевещание, резервирование, надежность

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GLOSSARY:

DVB-T2—Digital Video Broadcasting–Terrestrial 2
T2-MI—T2 Modulator Interface
PLP—Physical Layer Pipes
QoS—Quality of Service
QoE—Quality of Experience
SAE—Service Availability Error
SDE—Service Degradation Error
SIE—Service Impairment Error

INTRODUCTION

Regional adaptation at the DVB-T2 broadcasting stations may be performed by the use of local content inserters conforming to European Telecommunications Standards Institute specification—ETSI TS 102773. The most popular models are produced by ENENSYS Technologies, France (TxEdge T2), NPP Triada-TV, Russia (TTV-PLPSW-0401) and Nevion, Norway (CP330 T2-Bridge). Part of the main T2-MI stream containing multiplex package services may be updated

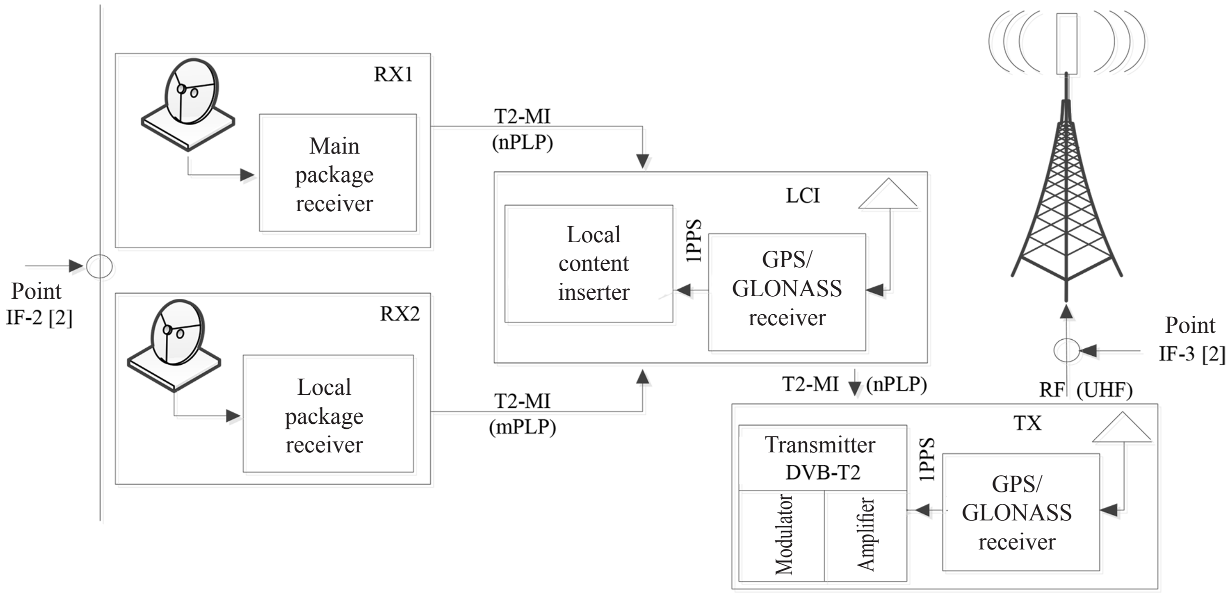

Fig. 1. A scheme for organizing broadcasting at a typical transmitting station

with the local content using PLP substitution. Setting the local content insertion device into operation implies installing an additional equipment to receive local TV channel packages, thus affecting the reliability parameters of the broadcasting system at the station as well as the Quality of Service (QoS) performance index.

According to GOST R 58912-2020 National Standard [1], "*the parameters of the end-to-end transmission of DTV signal at the broadcasting facility are used to assess the distortion of TV signal transmitted from the receiving point at digital transmitting stations before it reaches the land-based (terrestrial) digital TV stations. These parameters characterize the quality of the end-to-end TV signal transmission at two levels:*

- *video and audio quality of experience (QoE);*
- *QoS.*"

The reliability parameters are assessed at point IF-3 (Figure 7.1, Chapter 7 of the Handbook on Organizing Digital Terrestrial Television Broadcasting Networks and Systems Implementation [2]). Throughout the study, the section of broadcasting system within the limits of points IF-2 and IF-3 [2], which hardware is implemented at the remote typical transmitting station, is under consideration. As the paper deals with the transmitting section of a typical transmitting station, it would be reasonable to rest on the objective QoS assessment, since the direct-to-home receiving path has not been assessed here.

Since both parameters (subjective, QoE along with objective, QoS) are of equal significance, the paper aims at calculating the availability factor and reliability parameters of the broadcasting system as well as at determining the relationship between the availability factor and objective QoS assessment, which could be calculated using hardware for digital data stream control and analysis.

ASSESSMENT OF RELIABILITY PARAMETERS FOR THE TERRESTRIAL BROADCASTING SYSTEM

A scheme for organizing broadcasting including local insertions is generally shown in Fig. 1.

To calculate reliability, this scheme can be represented as two elements connected in parallel (equipment for receiving main RX1 and local RX2 streams) along with two elements connected in series: local content inserter (LCI) and DVB-T2 TX Transmitter.

A scheme for calculating reliability is presented in Fig. 2. In practical use of the broadcasting system with content modification, the source of local (modifying) T2-MI stream is usually not fully interchangeable with the source of the main one.

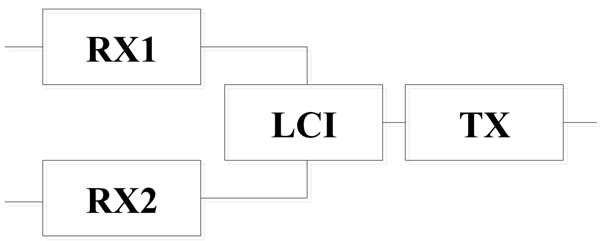

Fig. 2. A scheme for calculating reliability

Therefore, the following calculation is performed specifically for the case, when the system is operable with functioning of either both sources (i.e., insertion is performed), or only the main one (the signal of the main T2-MI package is transmitted without local insertion [3]). In this case, the local source would not replace the main one when the latter fails [4].

It would be ineffective to use the coefficient method for calculating reliability parameters in determining the availability of the broadcasting system, since a unit of equipment is considered as the system element. That means the implementation of hardware and software complex as a single facility, while there is no initial data on the coefficients of conditions and loads as well as on the basic failure and recovery rates for the modern equipment under consideration. Also, according to the analysis of the equipment documentation [5–7], there is no data on an average operating time between failures or other reliability parameters which would allow calculating the system availability factor. In this regard, the dynamic modeling method applying the system of differential equations of A.N. Kolmogorov [8] is used in this paper.

Conditions for calculating reliability parameters for the scheme shown in Fig. 2 may be characterized as follows:

1) the broadcasting system is recoverable, i.e., the failed component can be recovered and further used;
2) two or more components cannot fail simultaneously [8];
3) only one component can be recovered at a time [8];
4) RX1 and RX2 units are not interchangeable, and the system is operable with functioning of either RX1, or both RX1 and RX2. Here, it should be considered that different content may be broadcasted. The system is inoperable when either RX1, or both RX1 and RX2 fails; however, when these units are simultaneously operable, the insertion is performed;
5) the unit that is not actually operating cannot pass into the failure state;
6) the inoperable state of the system means the absence of broadcasting signal, but since the paper considers a remote unattended broadcasting station, the equipment preceding the failed unit remains operable and therefore can also fail, despite the overall inoperable state of the system.

Equipment failure may be characterized by the following conditions [9]:

- for the RX1 and RX2 units: interference effect on the quality of reception and transmission over the delivery channel; hop failure; failure on the side of the data stream formation; hardware and software failures of the receiver; signal errors resulting in broadcasting the output signal by the receiver incorrectly;
- for the LCI unit: hardware and software failure; insertion error; input signal errors preventing substitution; equipment synchronization problems;
- for the TX unit: hardware and software failure; signal errors preventing broadcasting; equipment synchronization problems; T2-MI delay mismatch.

The listed factors are considered when determining actual values of failure and restoration rates for specific equipment separately, calculated on the basis of the equipment operations manual similarly to the method proposed in [9]. Numerical values of failure and recovery rates are the following:

$$\lambda_1 = \lambda_2 = 0.00054;\ \lambda_3 = 0.00226;\ \lambda_4 = 0.00101;$$

$$m_1 = m_2 = 0.082;\ m_3 = 0.038;\ m_4 = 0.038.$$

The failure rate λ_1 and recovery rate m_1 refer to the RX1 unit, while λ_2 and m_2—to the RX2 unit, λ_3 and m_3—to LCI, and λ_4 and m_4—to TX, respectively. Factors affecting the reliability and operability of telecommunication equipment are also given in [10–12].

Table 1. System states when the sources are non-interchangeable

No.	System	RX1	RX2	LCI	TX
1	Operable	Operable	Operable	Operable	Operable
2	Operable	Operable	Failure	Operable	Operable
3	Recovery	Failure	Operable	Inoperable	Inoperable
4	Recovery	Operable	Operable	Failure	Inoperable
5	Recovery	Operable	Operable	Operable	Failure
6	Recovery	Failure	Operable	Failure	Inoperable
7	Recovery	Failure	Failure	Inoperable	Inoperable
8	Recovery	Failure	Operable	Inoperable	Failure
9	Recovery	Operable	Failure	Failure	Inoperable
10	Recovery	Operable	Failure	Operable	Failure
11	Recovery	Operable	Operable	Failure	Failure
12	Recovery	Failure	Failure	Failure	Inoperable
13	Recovery	Operable	Failure	Failure	Failure
14	Recovery	Failure	Failure	Inoperable	Failure
15	Recovery	Failure	Operable	Failure	Failure
16	Recovery	Failure	Failure	Failure	Failure

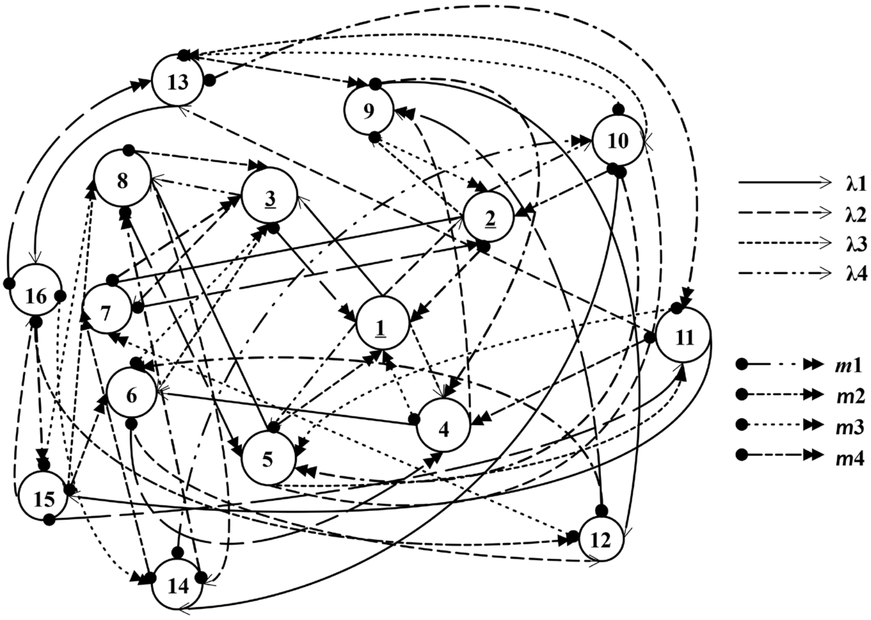

Fig. 3. A transition graph of the broadcasting system states
(the underlined numeration of a state corresponds to the system operability)

Table 1 shows possible states of the broadcasting system shown in Fig. 2. Table 1 demonstrates that when signal sources RX1 and RX2 are non-interchangeable, the system may have only two operable states. Figure 3 shows the transition graph of system states based on the tabled data.

The edges connecting the system states characterize the failure and recovery rates of the system components when transiting from one state to another.

For the resulting graph, the system of Kolmogorov differential equations may be written in the following general form:

$$\frac{d}{dx} p_i(t) =$$

$$= \left(\sum_{j,k} p_j(t) m_k + \sum_{j,k} p_j(t) \lambda_k \right) - p_i(t) \left(\sum_k m_k + \sum_k \lambda_k \right), \quad (1)$$

where $p_i(t)$ are values of the system state probabilities and $i \in [1, 2, \ldots 16]$ are the numbers of states according to Table 1 and points of graph (Fig. 3). In Eq. (1), the first summand describes edges comprising the vertex number i, while the second summand describes outcoming edges. For example, the equation for the state with number 3 may be written as follows:

$$\frac{d}{dx} p_3(t) = (\lambda_1 p_1(t) + m_3 p_6(t) +$$

$$+ m_2 p_7(t) + m_4 p_8(t)) - p_3(t)(\lambda_2 + m_1),$$

and other 16 equations have been derived in the same way.

The availability factor K_{AF1} is defined as follows:

$$K_{\text{AF1}}(t) = \sum_{i \in E^+} p_i(t) = p_1(t) + p_2(t).$$

The downtime rate K_{DT1} may be written as follows:

$$K_{\text{DR1}}(t) = \sum_{i \in E^-} p_i(t) = p_3(t) + p_4(t) + p_5(t) +$$

$$+ p_6(t) + p_7(t) + p_8(t) + p_9(t) + p_{10}(t) + p_{11}(t) +$$

$$+ p_{12}(t) + p_{13}(t) + p_{14}(t) + p_{15}(t) + p_{16}(t).$$

The failure stream is calculated as the sum of the products of failure rates and state probabilities during system transition from operable to non-operable state [8], as follows:

$$w_1 = \lambda_3 p_1 + \lambda_4 p_1 + \lambda_4 p_2 + \lambda_3 p_2 + \lambda_1 p_2 + \lambda_1 p_1.$$

The recovery stream is defined as the sum of the products of recovery rates and state probabilities during system transition from non-operable to operable state [8], as follows:

$$q_1 = m_4 p_5 + m_3 p_4 + m_4 p_{10} + m_1 p_7 + m_1 p_3 + m_3 p_9.$$

Based on calculations performed using *SimInTech* software [1], the steady-state availability factor amounts to 0.9144 while the downtime rate is 0.086. Steady-state values of the failure and recovery fluxes are equal to 0.0035, i.e., $w_1 = q_1 = 0.0035$.

The average time between failures in terms of nominal units may be written as follows [8]:

$$T_1 = {K_{\mathrm{AF1}}}/{w_1} = {0.9144}/{0.0035} = 261.26 \text{ units},$$

while the average time to recovery may be written in the following way [8]:

$$T_1^{\mathrm{rec}} = {K_{\mathrm{DT1}}}/{q_1} = {0.086}/{0.0035} = 24.57 \text{ units}.$$

According to GOST R 58020-2017 National Standard, the integral availability factor of the digital terrestrial television broadcasting network (from broadcasting of the Russian federal company to the bounders of the coverage area with normalized parameters) should amount at least to 0.9985 for broadcasting zones A and B. This value involves only calculations based on the reliability parameters of specific products/equipment provided by the manufacturer either with the availability factor value, or with the value of time between failures. These parameters are laid down by the manufacturer and are justified only by the software stability of a particular device, hardware quality, the ability to operate at different ambient temperatures, etc., that is, how long the device can operate performing its functions under other ideal external conditions.

It should be noted here that the paper deals with the reliability of the equipment at a typical unattended remote broadcasting station, rather than of the entire network, so the values of availability factors differ from those given in GOST National Standards. According to [14], "*the requirements to K_{AF} of the most mass network elements (for example, unattended radio transmitting television stations with low power transmitters) can be lower due to the fact that they provide service to isolated small towns*."

RELIABILITY OF THE BROADCASTING SCHEME USING NON-INTERCHANGABLE SOURCES WITH ADDITIONAL REDANDUNCY

If the scheme shown in Fig. 2 is supplemented by connecting the output of the main stream source to the input of the transmitting device bypassing the modification system, then the number of operable states of the system may certainly increase.

Figure 4 shows a scheme of redundant connection.

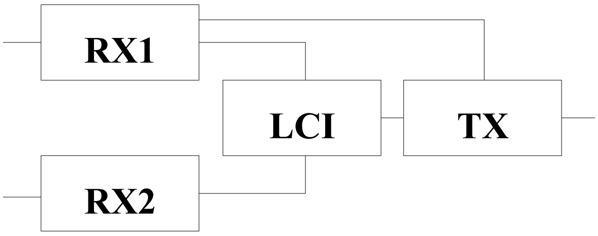

Fig. 4. A scheme with additional redundancy for calculating reliability

In case the insertion unit fails, the signal from RX1 is transmitted directly to TX, as well as the unmodified signal is broadcasted, but when the transmitting station operates in a single-frequency mode, a difference in time delays between the signal which has not passed LCI unit at the considered station and the signal which has passed LCI unit at the neighboring single-frequency zone station may occur. This, as well as the fact that broadcasting an unmodified signal may also represent an abnormal operating mode, should be considered when actually using the broadcasting network.

System states are shown in Table 2, whence it follows that under the given conditions there become more operable system states than in Table 1. The transition graph of the system states is plotted in the same way as

Table 2. States of broadcasting system with additional redundancy

No.	System	RX1	RX2	LCI	TX
1	Operable	Operable	Operable	Operable	Operable
2	Operable	Operable	Failure	Operable	Operable
3	Recovery	Failure	Operable	Inoperable	Inoperable
4	Operable	Operable	Operable	Failure	Operable
5	Recovery	Operable	Operable	Operable	Failure
6	Recovery	Failure	Operable	Failure	Inoperable
7	Recovery	Failure	Failure	Inoperable	Inoperable
8	Recovery	Failure	Operable	Inoperable	Failure
9	Operable	Operable	Failure	Failure	Operable
10	Recovery	Operable	Failure	Operable	Failure
11	Recovery	Operable	Operable	Failure	Failure
12	Recovery	Failure	Failure	Failure	Inoperable
13	Recovery	Operable	Failure	Failure	Failure
14	Recovery	Failure	Failure	Inoperable	Failure
15	Recovery	Failure	Operable	Failure	Failure
16	Recovery	Failure	Failure	Failure	Failure

the graph for the system without redundancy, therefore, it is not presented in the paper for the sake of brevity.

The system of differential equations based on data given in Table 2 may be also created using Eq. (1).

Thus, the availability factor is defined as follows:

$$K_{\mathrm{AF2}}(t)=\sum_{i\in E^{+}} p_i(t)=p_1(t)+p_2(t)+p_4(t)+p_9(t),$$

while the downtime rate may be written in the following way:

$$K_{\mathrm{DT2}}(t)=\sum_{i\in E^{-}} p_i(t)=p_3(t)+p_5(t)+p_6(t)+$$
$$+p_7(t)+p_8(t)+p_9(t)+p_{10}(t)+p_{11}(t)+$$
$$+p_{12}(t)+p_{13}(t)+p_{14}(t)+p_{15}(t)+p_{16}(t).$$

The failure stream may be defined as follows:

$$w_2=\lambda_4 p_1+\lambda_4 p_2+\lambda_1 p_1+\lambda_4 p_4+\lambda_1 p_4+$$
$$+\lambda_1 p_9+\lambda_4 p_9+\lambda_1 p_2,$$

while the recovery stream may be written in the following way:

$$q_2=m_4 p_5+m_4 p_{10}+m_1 p_7+m_1 p_3+m_1 p_6+$$
$$+m_4 p_{11}+m_1 p_{12}+m_4 p_{13}.$$

In steady-state mode, the availability factor calculated for this broadcast scheme using *SimInTech* environment amounts to 0.967, the steady-state value of the failure stream as well as the recovery stream is 0.0015, i.e., at $t\to\infty$, $w_1=q_1=0.0015$. The steady-state downtime design rate is 0.032.

The average time between failures may be written in nominal units in the following way:

$$T_2={K_{\mathrm{AF2}}}\big/{w_2}={0.967}\big/{0.0015}=644.67\ \text{units},$$

while the average time to recovery may be written as follows:

$$T_2^{\mathrm{rec}}={K_{\mathrm{DT2}}}\big/{q_2}={0.032}\big/{0.0015}=21.33\ \text{units}.$$

Thus, the following conclusions have been drawn from the research.

When using direct non-standard redundancy, the availability factor of the broadcasting system at a typical transmitting station with content modification is 5.26% higher than that of a similar scheme without redundancy.

Conversion to the physical time shows that the redundancy allows reducing the equipment downtime by 19 days, 4 hours and 47 minutes per year.

With the equipment recovery time being almost equal, the average time between failures for the system with redundancy is 2.5 times higher than for that without redundancy, which corresponds to a longer operability interval for the complete set of equipment at a typical transmitting station.

It should be noted that the calculated availability factors for the set of equipment at the remote transmitting station are practical, not regulatory values been determined for the worst-case scenario with allowance for the influence of possible external factors. In the paper, the probability of all the assumed faults happening to the equipment during the considered period is taken as one unit (worst-case scenario); however, this probability may be much lower in actual use.

RELATION OF THE AVAILABILITY FACTOR AND QOS COMPONENTS

According to the Guidelines on Measurements for Digital Terrestrial Television Broadcasting Systems [15], developed by the International Telecommunication Union (ITU), QoS is characterized by the following three main parameters:

- Service Availability Error (SAE);
- Service Degradation Error (SDE);
- Service Impairments Error (SIE).

The numerical values for these parameters are determined on the basis of the data stream analysis for certain errors of the first, second or third priority, according to ETSI TS 101290. Based on formulas for calculating the parameters given in [15], it may be assumed that in steady-state mode $SAE\to 0$, $SDE\to 0$, $SIE\to 0$. For the considered case with additional redundancy, the steady-state mode is defined at $t\in[225;\infty)$.

Thus, the quality of service could be also assessed in a steady-state mode only. The considered scheme for organizing broadcasting with additional redundancy has two automatic recovery points for digital stream:

- redundancy in LCI unit during the system transition from state 1 to state 2 and from state 5 to state 10 and back;
- redundancy in TX unit during the system transition from state 1 to state 4 and from state 2 to state 9 and back.

Automatic redundancy for TX implies switching from the main source of digital data stream (LCI device) to the redundant one (receiver of the federal signal RX1) in the event of a certain number of errors in the stream or complete absence of packages within a specified time. Automatic redundancy for LCI implies transition from the insertion mode when both streams from RX1 and RX2 are used to broadcasting only the basic T2-MI version from RX1 when errors occur in local digital stream. Reverse switching is possible when the main source is recovered and a specified number of correct packages are available. The absence of the main stream packages or errors during the waiting time when transiting to redundancy results in QoS decrease, in particular by SAE and SDE parameters (TS_sync_loss, PAT_error, PMT_error, PCR_error). Depending on the conditions of redundant switching, the decrease in QoS by these parameters causes short-term absence of the image on the subscriber receiver screen, image pixelation and typical image splitting into blocks. Also, redundancy may result in content replacement in the service subjected to modification by the main scheme. Reverse switching to the main source is less problematic, since it occurs in the absence of errors, but can also cause a decrease in QoS, in particular by SIE parameter (Continuity_count_error, Transport_error), which at a single occurrence can be unnoticed by the subscriber's subjective perception, except for changing the content of the modified channel. Moments of automatic redundancy for the system under consideration refer to the transient mode and are limited to time interval $t \in (0; 225)$, so the percentage of time providing a subscriber with the signal of a given quality may be directly characterized by the availability factor, i.e., with an appropriate QoS for a selected time period.

CONCLUSIONS

Calculations of reliability parameters for LCI system at a typical DVB-T2 transmitting station using the system of differential equations of Kolmogorov have determined that at practically equal time of equipment recovery with and without additional redundancy, the average operating time between failures of the system with redundancy is 2.5 times higher than of that without redundancy, which corresponds to a longer interval of operability of the entire typical TV broadcasting complex as well as to a less impact on QoS parameter. In addition, a decrease in QoS is conditioned by switching the equipment to redundant sources in case of automatic redundancy due to the absence of T2-MI stream packages during waiting time, as well as during reverse switching to the normal operational scheme in case the main source of the signal is recovered.

Authors' contribution. All authors equally contributed to the research work.

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