Dependability Measures for Access Networks and Their Evaluation

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Abstract—**One of the most important characteristics of any communication networks is dependability, and the dependability requirements are increasing with the expansion and intensification of usage of information and communication systems. This paper analyzes dependability measures for access networks and gives recommendations for their usage. The existing measures such as availability and the Failure Impact are discussed. To assess the dependability from the network operator's point of view, it is proposed to use the effectiveness retention ratio. It allows evaluating the whole network taking into account various partial failures. Methods for calculating this measure are given and its relationships with other measures, in particular, with end-to-end and full-end network availability, are revealed.**

I. Introduction

The huge role that information and communication technologies play in the modern world makes it extremely important to ensure dependability of communication networks. Failures can lead to significant monetary and image losses for both consumers of communication services and network operators. One of the first steps in solving dependability assurance problems is to select appropriate quantitative measures. On the one hand, they should be quite simple and clear, and on the other hand, reflect the impact of failures on consumers and network operators.

The purpose of this paper is to analyze dependability measures for access networks and give recommendations for their usage. Failures in these networks can lead to loss of communication and interruption of all services for consumers. However, for economic reasons, these networks are usually not as extensive as the core ones, and they are less likely to use redundancy and protection. Therefore, they require a thorough dependability analysis. A typical example of a modern access network is the Passive Optical Network (PON) discussed in the paper. However, this is only an example, and the results of the paper apply not only to PONs, but also to other access networks, in particular, to Radio Access Networks in mobile telecommunication systems.

When analyzing the dependability of communication networks, the viewpoints of end-users and network operators are considered [1], [2]. Dependability measures for these two perspectives may differ. The most commonly used in information and communication technologies dependability measure is availability (see, for example, [2], [3]). For communication networks can be considered end-to-end and full-end network availability [2]. An interesting dependability measure for access networks called Failure Impact was introduced in [4] for modeling the impact of a failure in irrational environment, where a network operator is worried about big failures disconnecting many customers.

An important feature of communication networks that is not taken into account by traditional dependability measures is the existence of partial failures. To account for such failures in complex systems, it was proposed to use the effectiveness retention ratio (ERR) [5]. Since this dependability measure is not commonly known, its definition and calculation methods are provided. Then possible approaches to determining the ERR for access networks are described. Besides that, relationships between the ERR and the previously considered measures, in particular, end-to-end and full-end network availability, are revealed.

The rest of the paper is organized as follows. Section II presents the basic concepts of dependability and two viewpoints on the dependability of communication networks: from the perspectives of network end-users and operators. Section III describes and analyses existing dependability measures for access networks: network availability (end-to-end and full-end) and Failure Impact. Section IV describes the possibilities and options for applying the effectiveness retention ratio as a dependability measure for access networks. It provides the definition and calculation methods for this measure, reveals its relationship to the dependability measures discussed earlier. Concluding Section V gives main findings obtained in the paper and possible direction for future work.

II. Dependability and its measures

A. Basic concepts

According to the basic terminological International Standard [6], dependability is defined for an item as its ability to perform as and when required. The same definition is repeated in the well-known International Standard ISO 9000 [7]. This is not by chance, since, under the agreement between International Electrotechnical Commission (IEC), International Organization for Standardization (ISO) and International Telecommunication Union (ITU) that constitute the World Standards Cooperation, it is the IEC, or rather its horizontal Technical Committee (TC) 56 "Dependability", that plays the leading role in standardizing in this area [8] (the author of [8] is the Chairman of IEC TC 56).

Among the many IEC standards for dependability there are two specifically devoted to communication networks: [1] and [2].

Dependability is used as a collective term for the time-related quality characteristics of an item and it includes availability, reliability, recoverability, maintainability, and maintenance support performance and, in some cases, other characteristics [6].

An item in this standard is defined as a subject being considered. It may be an individual part, component, device, functional unit, equipment, subsystem, or system. The item may consist of hardware, software, people or any combination thereof. In this paper, both the network as a whole and its components (nodes, links, devices) will be considered as items.

It is worth also briefly discussing the relationship between the concepts of dependability and reliability. As already mentioned, according to the [6], dependability is a broader concept that includes reliability. Herewith, reliability is ability to perform as required, without failure, for a given time interval, under given conditions.

However, the term “reliability” appeared earlier and quite often it is used in a broad sense instead of the term “dependability”, i.e. as a blanket term that includes abovementioned characteristics [8]. This use of the term “reliability” is found in numerous publications (including some of the references mentioned in this paper), journal titles, conferences, and so on. But this paper uses the terminology according to the standard [6].

B. Dependability measures

A dependability measure is a quantitative index of one or more characteristics that make up dependability of an object. In accordance with the main dependability characteristics, the standard [6] distinguishes reliability measures, maintainability and maintenance support measures, availability measures. For example, well-known measures are the mean operating time between failures (MTBF) for reliability and the mean time to restoration (MTTR) for maintainability.

Dependability measures are used for setting dependability requirements, dependability assessment of various technical solutions for comparison, dependability verification during commissioning and monitoring during operation. The correct choice of dependability measures is a very important task. Their inappropriate choice can lead to errors in assessment and selection of technical solutions, unnecessary costs, etc.

It is desirable that the dependability measure characterizes the impact of failures of an item on its intended use. Dependability measures of sub items should allow assessing the dependability of the item as a whole.

C. Two viewpoints on network dependability

There are two scenarios of interest to communication network dependability [1], [2]:

- from the perspective of network end-users,
- from the network operator perspective.

The former reflects the requirements and satisfaction of customers. It is important for regulating the relationship between them and network operators or network service providers. In particular, appropriate dependability measures and objectives for them should be included in Service Level Agreements (SLAs) [9]. The requirements of customers and the actual values of dependability measures for them can be different. Therefore, a set of different values is obtained for the network.

To assess reliability from the network operator’s point of view, it is desirable to have not a set of values, but one or a few dependability measures that give a general vision of the entire network. It will be useful for solving various tasks, in particular:

- accounting for dependability in the network planning and comparison of possible variants,
- comparison of operational network dependability in different territories,
- comparison of operational network dependability at different time intervals (month, quarter, year) and identification of trends.

In general, an analogy is relevant here with the fact that the ITU-T Recommendations on Quality of Service (E.800, E.802, G.1000) also distinguish customer's and service provider’s viewpoints.

III. The existing measures

A. Availability

The most commonly used in information and communication technologies dependability measure is availability (see, for example, [2], [3]).

The standard [6] provides several availability related measures. The first among them is the instantaneous (point) availability. It is the probability that an item is in a state to perform as required at a given instant. The steady state (asymptotic) availability is the limit, if it exists, of the instantaneous availability when the time tends to infinity. It is most commonly used in practice and is usually called merely availability and denoted by A. As a rule, it may be expressed as the ratio of the mean up time to the sum of the mean up time and mean down time. Most often, availability is calculated using the formula

$$A = \frac{MTBF}{MTBF + MTTR}.$$

Unavailability, denoted by U, is defined as the probability of the opposite event and is a complement of availability to one:

$$U = 1 - A = \frac{MTTR}{MTBF + MTTR}.$$

Availability or unavailability can be expressed also through a downtime per year or other time period. For example, SLAs often refer to monthly downtime in order to calculate service credits to match monthly billing cycles. Downtime for the period T corresponding to the availability A or unavailability U is calculated by the formula

$$D_T = (1 - A) \cdot T = U \cdot T .$$

Availability corresponding to the downtime D_T can be expressed as

$$A = 1 - \frac{D_T}{T} . \tag{1}$$

An extensively used measure for communication networks is end-to-end network availability [2]. It can be defined as the probability that an operable path exists between the specified pair of endpoints and describes the availability for customers connected to these points. In access networks, end-user connection points and the central node are usually taken as endpoint pairs.

Availability of the entire network from the network operator perspective in [2] is characterized by full-end network availability. It is denoted by A_N and is determined as follows:

$$A_N = 1 - \frac{1}{T} \sum_j D_{Tj} P_j , \tag{2}$$

where T is the time period under consideration (in [2] $T = 1$ year), D_{Tj} is the downtime for this period of end-to-end service path j, P_j is the number of users in service path j divided by the total number of users in the whole network.

Thus, full-end network availability is determined by a weighted sum of downtimes of all network service paths. Therefore, it is not really availability in the sense of the definition from [6], since it is not defined as the probability that some item is in the up state. The more correct meaning of full-end network availability will be revealed below.

B. Failure Impact

An interesting dependability measure for access networks called Failure Impact (*FI* in formulas) was introduced in [4]. It is intended for modeling the impact of a failure in a so called irrational environment, where a network operator is worried more about a big failure disconnecting all customers for one hour at the same time (negative release on press, newspapers, TV leading to bad publicity) than for multiple small failures throughout the year disconnecting every customer for one hour on average.

In [4] the Failure Impact used to evaluate and compare different protection architectures for PON. It gives a view from the network operator perspective. However, the definition and calculation of this measure in [4] raise a number of questions, which will be stated below.

1) A rational environment: Initially, the Failure Impact was defined for a rational environment [4]. In this situation it is proportional to the number of customers disconnected by the failure, N, and the unavailability of the component, U. This leads to the definition:

$$FI = N \cdot U . \tag{3}$$

For example, for $N = 1000$ customers, $U = 10^{-5}$ and $N = 100$ customers, $U = 10^{-4}$, in a rational environment we have the same result $FI = 0.01$.

In this definition it is assumed that all customers have the same unavailability, but in reality this may not be the case. Besides that, it is assumed that when a component fails, all customers lose their connections. Actually, there are many components in a network, their unavailability can be different and their failures can lead to different consequences, i.e., loss of connections for different numbers of customers. What values N and U should be put in (3) in such situations, for which component?

Indeed, consider typical examples of PON topology shown at Fig. 1 (OLT – Optical Linear Terminal in the central node, ONU – Optical Network Unit in customer premises, PLC – Planar Lightwave Circuit splitter). Each OLT port serves 64 customers, but the number of splitting stages and the types of splitters are different (2×4×8 = 4×4×4 = 8×8 = 16×4 = 64).

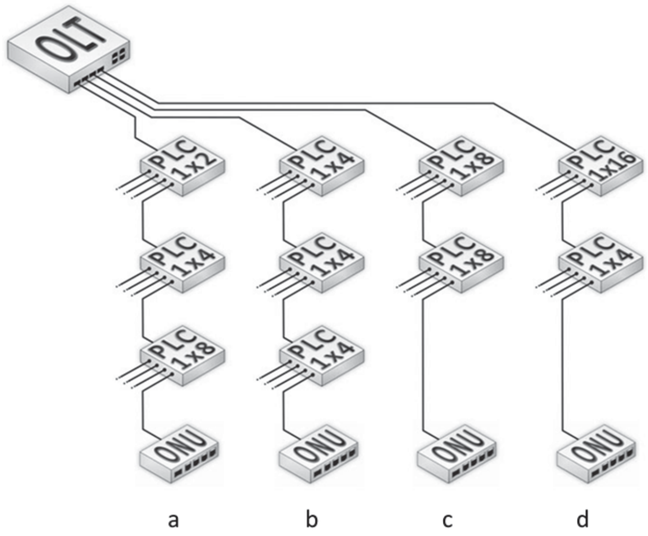

Fig. 1. Typical examples of PON topology

Failure of OLT, the upper splitter or feeder fiber between it and OLT leads to loss of connections for all 64 customers. On the other hand, the failure of a lower splitter leads to a loss of connections for some customers: for 8 in cases *a* and *c*, for 4 in cases *b* and *d*. Intermediate situations are also possible in cases *a* and *b*. And lastly, failure of ONU or a distribution fiber leads to the loss of connection for only one customer.

2) An irrational environment: The Failure Impact in an irrational environment was given by:

$$FI = N^{\alpha} \cdot U , \tag{4}$$

where the parameter α denotes “irrationality” in the behavior of network operators, $\alpha > 1$ (growing α leads to more and more irrationality); for a rational situation $\alpha = 1$.

For example, if $\alpha = 2$, for $N = 1000$ customers, $U = 10^{-5}$ and $N = 100$ customers, $U = 10^{-3}$, we have the same result $FI = 10$, although the product $N \cdot U$ is 0.01 in the first case and 0.1 in the second.

More generally, the failure impact can be defined as $\mathrm{FI} = f(N)\cdot U$, where f is some function, for which the ratio $f(N)/N$ grows monotonously with the growth of N, and when the factor of irrationality $\alpha = 1$, $f(N) = N$ [4].

3) Impact of combination of failures: In case of different non-simultaneous failures, the impact of these events can be summed, leading to additivity. Later in [4], the formula for calculating the Failure Impact in the case of two failures occur simultaneously is deduced. It follows from this formula that the additivity in this case is only approximate and under the assumption that all the values of unavailability are small ($U_i \ll 1$). This definition was then applied to two specific cases: two parallel links and two serial links.

Unfortunately, for these cases, not everything is clear. Parallel links are used for protection, so that customers do not suffer from a single failure, everything is clear here. However, what are serial links? It is questionable to assume that the number of customers connected to each of them is the same, as is done in [4]. For example, failures of the feeder fiber (between OLT and the upper splitter) and a distribution fiber (adjacent to ONU) affect a different number of customers (see Fig. 1). These two links can be considered serial for some customers, but they are not serial for other customers.

Besides that, the Failure Impact depends on the number of customers in the network and its values can take any positive values (for the examples considered in [4], the obtained values are in the range from $3\cdot10^{-3}$ to $3\cdot10^{4}$). This makes it difficult to compare different networks using this measure. From this point of view, it is more convenient when the measure is normalized, i.e. its values lie in the range from 0 to 1, such as availability.

The next section proposes a general dependability measure. In one of its special cases, it allows keeping the main idea of the Failure Impact, but does not have the above-mentioned disadvantages of the latter.

IV. Effectiveness retention ratio

A. Foundation, standardization, definition and basic properties

All traditional dependability measures are defined under the assumption that an item being considered can be in one of two states: up (available), in which it is able to perform as required, and down (unavailable), in which it is unable to perform as required due to internal fault or preventive maintenance. Availability is the probability of being in the up state; unavailability is the probability of being in the down state.

Nevertheless, many complex systems can have intermediate states that they go to as a result of partial failure. These states are characterized by the loss of some, but not all, required functions or by reduced performance. For example, the consequences of failures of various PON components were discussed above. Some of these failures are complete from a system point of view, while others are partial.

To assess the dependability of such systems, an approach is known related to the evaluation of system effectiveness [10]. However, in [10] absolute values of effectiveness are considered, which is inconvenient when comparing different systems with each other. It is more reasonable to use relative effectiveness and to define a normalized dependability measure on this basis, the values of which will be between 0 and 1.

This measure is called the effectiveness retention ratio (ERR). In some publications, it is also called efficiency ratio, but according to author's opinion, this term less accurately expresses its meaning. It realizes the idea expressed in the classic monograph [11], according to which for complex systems the dependability of the system should be understood to mean the stability of the effectiveness with consideration of the reliability of the parts composing the system.

Unfortunately, the ERR is not included in the international terminological standard for dependability [6]. However, it is in the regional standards [12], [13] adopted by the Interstate (Euro-Asian) Council for Standardization, Metrology and Certification of the Commonwealth of Independent States. In [12] there is the definition of the ERR, [13] provides scope and recommendations for its usage. The ERR is discussed in detail in [14].

The ERR is defined as follows:

$$ERR = \frac{E}{E_0}, \tag{5}$$

where E is an index of effectiveness of using the system, E_0 is the nominal value of this index calculated under the condition that failures do not occur.

The index of effectiveness is usually defined as the expectation of the output effect of the system. Particular form of the output effect depends on the nature of the considered system. Examples of its designation for communication networks will be discussed below.

It is clear from the definition that $0 \le ERR \le 1$, because $E \le E_0$. The closer the ERR to one, the higher the dependability.

The formula (5) provides a definition of the ERR, but is not suitable for calculating it in practice. On the contrary, E can be found as the product of E_0 and the ERR if necessary. General methods that can be used for calculation the ERR are described in [10], [14], [5] and some other publications; for access networks they will be presented below.

B. Mathematical description and general calculation methods

Consider a system consisting of n elements, each of which can be in one of two states: up and down. States of elements are assumed to be statistically independent. Denote the indicator of the ith element's state by x_i:

$$x_i = \begin{cases} 1, \text{if the ith element is in up state;} \\ 0, \text{if the } i\text{th element is in down state.} \end{cases}$$

To describe the state of the system, an n-dimensional binary vector $\mathbf{x} = (x_1,\ldots,x_n)$ is introduced. If all system states can be divided into up and down states, a structural function can be defined for the system [15]:

$$\varphi(\mathbf{x}) = \begin{cases} 1, \text{if the state } \mathbf{x} \text{ is the up state for the system;} \\ 0, \text{if the state } \mathbf{x} \text{ is the down state for the system.} \end{cases}$$

Then $S_1 = \{\mathbf{x} \mid \varphi(\mathbf{x}) = 1\}$ is the subset of all up states and $S_0 = \{\mathbf{x} \mid \varphi(\mathbf{x}) = 0\}$ is the subset of all down states for the system.

Structural functions satisfy the following conditions [15]:

$$\begin{aligned} &\varphi(0,\dots,0) = 0; \\ &\varphi(1,\dots,1) = 1; \\ &\text{if for all } i = 1,\dots,n \ \ x_i \le y_i, \text{ then } \varphi(\mathbf{x}) \le \varphi(\mathbf{y}). \end{aligned} \tag{6}$$

To account for partial failures in complex systems, we introduce an effectiveness function also denoted $\varphi(\mathbf{x})$ that generalizes the structural function. It can have not only the values 0 and 1, but any values in the range from 0 to 1. The value $\varphi(\mathbf{x})$ is the relative output effect of the system in the state $\mathbf{x}$. Its maximum value, which is reached when all elements are in up state, is taken as one. Effectiveness functions also satisfy the conditions (6).

By the way, in this case, we can also assume that the subsets of up and down states for the system exist, but they are not ordinary subsets, but fuzzy ones [16]. Their membership functions are $\varphi(\mathbf{x})$ for the subset of up states and $1 - \varphi(\mathbf{x})$ for the subset of down states.

Then the ERR is the mathematical expectation of $\varphi(\mathbf{x})$ [5]:

$$ERR = \mathbf{E}[\varphi(\mathbf{x})] = \sum_{\mathbf{x}} \varphi(\mathbf{x}) p(\mathbf{x}) . \tag{7}$$

Here $p(\mathbf{x})$ is the probability that the system is in the state $\mathbf{x}$:

$$p(\mathbf{x}) = \prod_{i=1}^{n} A_i^{x_i} U_i^{1-x_i} ,$$

where A_i and $U_i = 1 - A_i$ are the availability and unavailability of the ith element.

Of course, direct calculation using formula (7) is only possible when the number of elements n is small, since the number of states is 2^n and it increases exponentially with the growth of n.

If for all elements $U_i << 1/n$, the ERR can be calculated approximately using the formula [10]

$$ERR \approx 1 - \sum_{i=1}^{n} U_i (1 - \omega_i) , \tag{8}$$

where ω_i is the relative output effect of the system in the state when only one ith element is failed:

$$\begin{aligned} &\omega_1 = \varphi(0,1,\dots,1), \\ &\dots \\ &\omega_n = \varphi(1,\dots,1,0) \end{aligned}$$

($1 - \omega_i$ can be considered as a necessity index for the ith element).

The formula (8) takes into account only states that have no more than one failed element. It gives a lower bound for the ERR and the error of this approximation is not greater than [10]

$$\delta = \frac{n(n-1)}{2} \left(\max_{i=1,\dots,n} U_i \right)^2 .$$

For example, if $n = 100$ and $U_i \le 10^{-4}$, then $\delta \approx 10^4 \cdot (10^{-4})^2/2 = 0.5 \cdot 10^{-4}$ and the calculation using the formula (8) gives three digits after the decimal point.

C. The ERR for access networks

1) A rational environment: For the rational environment, it is natural to assume that the output effect of access network is proportional to the number of connected customers ν. Then

$$\varphi_R(\mathbf{x}) = \frac{\nu}{N_0} ,$$

where N_0 is the total number of customers.

In this case, according to (3) the loss from failures is proportional to the number of disconnected customers $N_0 - \nu$, that gives the same expression:

$$1 - \varphi_R(\mathbf{x}) = \frac{N_0 - \nu}{N_0} = 1 - \frac{\nu}{N_0} .$$

Let $\varphi_j(\mathbf{x})$ be a structural function for the connection of the jth customer:

$$\varphi_j(\mathbf{x}) = \begin{cases} 1, \text{if in the state } \mathbf{x} \text{ the } j\text{th customer is connected;} \\ 0, \text{if in the state } \mathbf{x} \text{ the } j\text{th customer is disconnected.} \end{cases}$$

Then

$$\nu = \sum_{j=1}^{N_0} \varphi_j(\mathbf{x}) . \tag{9}$$

Since

$$\mathbf{E}[\varphi_j(\mathbf{x})] = \mathbf{P}\{\varphi_j(\mathbf{x}) = 1\} = A_{Cj} , \tag{10}$$

where A_{Cj} is the availability for the jth customer, we get from (9) that

$$ERR_R = \frac{\mathbf{E}\nu}{N_0} = \frac{1}{N_0} \mathbf{E}\left[\sum_{j=1}^{N_0} \varphi_j(\mathbf{x}) \right] = \frac{1}{N_0} \sum_{j=1}^{N_0} A_{Cj} = \overline{A}_C . \tag{11}$$

Thus, in this case, the ERR is equal to the average availability for all customers $\overline{A}_C$. If the values of availability A_{Cj} are the same for all customers, the ERR is equal to this common value.

Expressing A_{Cj} using the formula (1) and substituting in (11), we get the following:

$$ERR_R = \frac{1}{N_0} \sum_{j=1}^{N_0} A_{Cj} = \frac{1}{N_0} \sum_{j=1}^{N_0} \left(1 - \frac{D_{Tj}}{T} \right) = 1 - \frac{1}{T} \sum_{j=1}^{N_0} D_{Tj} \cdot \frac{1}{N_0} .$$

Comparing this expression with (2), we see that the full-end network availability defined in [2] is actually the ERR. In this case, the service paths correspond to customers and for all of them $P_j = 1/N_0$.

2) An irrational environment: For the irrational environment the output effect is expressed as a non-linear function of the number of customers. As in [4], consider a simple case where this is a power function. Namely, in accordance with (4), the loss from failures is proportional to the number of disconnected customers $N_0 - \nu$ in power $\alpha > 1$. Thus for the relative output effect we have:

$$\varphi_I(\mathbf{x}) = 1 - \frac{(N_0 - \nu)^\alpha}{N_0^\alpha} . \tag{12}$$

The ERR can be calculated as follows:

$$ERR_I = \sum_{z=1}^{N_0} \left[1 - \frac{(N_0 - z)^\alpha}{N_0^\alpha} \right] \cdot \mathbf{P}\{\nu = z\} . \tag{13}$$

However, calculating probabilities $\mathbf{P}\{\nu = z\}$ may be too complicated, so formula (13), as well as (7), is usually not suitable for practical calculations. In this situation the approximate formula (8) can be used. Denote by N_i the number of customers disconnected due to the failure of the *i*th element. Then

$$\omega_i = 1 - \frac{N_i^\alpha}{N_0^\alpha}$$

and according to (8)

$$ERR_I \approx 1 - \frac{1}{N_0^\alpha} \sum_{i=1}^{n} U_i N_i^\alpha .$$

For any state $\mathbf{x}$ there is an inequality $\varphi_I(\mathbf{x}) \geq \varphi_R(\mathbf{x})$. Indeed,

$$1 - \frac{\nu}{N_0} \leq 1 \Rightarrow \left(1 - \frac{\nu}{N_0}\right)^\alpha \leq 1 - \frac{\nu}{N_0} \Rightarrow \frac{\nu}{N_0} \leq 1 - \frac{\left(N_0 - \nu\right)^\alpha}{N_0^\alpha} .$$

Therefore,

$$ERR_I = \mathbf{E}[\varphi_I(\mathbf{x})] \geq \mathbf{E}[\varphi_R(\mathbf{x})] = ERR_R = \overline{A}_C .$$

On the other hand, using results [17], it is possible to get an upper bound for the ERR_I. Precisely, since the right side of the equality (12) as a function of ν is concave, the upper bound is obtained by substituting $\mathbf{E}\nu = N_0 \cdot \overline{A}_C$ instead of ν into this function (this follows from Jensen's inequality [18]). After doing this, we get that

$$ERR_I \leq 1 - \left(1 - \overline{A}_C\right)^\alpha = 1 - \overline{U}_C^{\,\alpha} .$$

3) Consideration of differences between consumers: In the above considerations, all customers were regarded equal, so the output effect only depended on the number of connected customers. In reality, this may not be the case. Other definitions of the output effect allow taking into account the difference between customers. For example, the output effect can be equal to the average total amount of traffic transmitted in the network per time unit. In this case

$$\varphi(\mathbf{x}) = \sum_{j=1}^{N_0} w_j \varphi_j(\mathbf{x}) , \tag{14}$$

where w_j is the *j*th customer share in the total traffic amount.

Taking the mathematical expectation from the both sides of (14) and using (10), we get in this case that the ERR is equal to the weighted sum of availabilities for all customers

$$ERR = \sum_{j=1}^{N_0} w_j A_{Cj} , \tag{15}$$

In general, weights w_j reflect importance of customers. They may, for example, depend on tariff plans, SLA terms, etc. The weights should meet the conditions

$$0 \leq w_j \leq 1, \quad \sum_{j=1}^{N_0} w_j = 1 .$$

In (11) $w_j = 1/N_0$ for all *j*.

It is easy to find that the full-end network availability according to (2), when P_j are different, is also equal to the ERR according to (15) with $w_j = P_j$.

V. Conclusion

The huge role of information and communication technologies in the life of modern society makes dependability a very important factor for communication networks. One of the first steps in solving dependability assurance problems is the selection of appropriate measures.

This paper analyzes the dependability measures for access networks. On this basis, the following recommendations are given for their selection and use. The main measure for assessment dependability from the end-user's point of view is end-to-end network availability, which is usually used in SLAs. The most appropriate measure for assessment dependability from the operator's point of view is the effectiveness retention ratio. It was introduced to assess the dependability of complex systems where partial failures are possible. The ability to select different output effects gives it flexibility. Therefore, the effectiveness retention ratio is suitable for both rational and irrational environments, and allows taking into account differences between customers.

Besides that, the paper reveals the relationships between the effectiveness retention ratio and network availability. In particular, formulas are derived for calculating the effectiveness retention ratio through values of end-to-end availability. It is shown that the full-end network availability introduced in the standard IEC 62673:2013 is actually a special case of the effectiveness retention ratio.

Future work in this context will include developing more detailed recommendations for determining the output effect in various situations that can take place in practice.

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