Analysis of the operational readiness of telecommunication networks

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Abstract. The article discusses telecommunication communication networks of various topologies. The definition of the operational readiness coefficient is given. The analysis of various networks of different topologies for the reliability of information transmission is carried out. Comparison of the reliability of the ring and radial topologies in terms of the operational availability factor is carried out.

1. Introduction
It is extremely difficult to increase the reliability of telecommunication communication networks (TCN) during operation. This is due to the fact that reliability is mainly based on the design of networks and the manufacture of equipment, and during operation, the reliability only decreases. The rate of decrease in reliability depends on the operating methods, the qualifications of the maintenance personnel, and the operating conditions.

There are effective methods to improve reliability:

- reservation;
- simplification of the system;
- the use of the most reliable elements;
- standardization and unification of elements and assemblies;
- built-in control;
- automation of checks.
The effectiveness of these methods lies in the fact that they allow building reliable systems from low-reliable elements. These methods can reduce the failure rate of the system, reduce the mean recovery time, and increase the uptime of the system.

2. Formulation of the problem

Considering the TCN as a complex recoverable system, it is possible to define its reliability as the coefficient of operational readiness for a given time according to the formula [1-2]:

\[ K_{or}(t) = K_r P(t), \]  

where \( P(t) \) – conditional probability of failure-free operation of the system in time \( t \), provided that the system is ready for operation at an arbitrary moment; \( K_r \) – availability factor, is defined as the limit of the instantaneous availability factor when the considered moment of time tends to infinity, the instantaneous availability factor (availability function) is the probability that an object will be in a working state at a given time [3].

The network operational readiness factor is defined as the probability that the network will be operational at an arbitrary point in time, except for the planned periods during which the object is not intended to be used for its intended purpose, and, starting from this moment, it will work flawlessly for a given interval time [3].

The most important distinguishing feature of the TCN is the network topology, the properties of which can be changed during operation depending on the tasks being solved, for example, ensuring high reliability indicators. The TCN uses the following network topologies [4].

- Fully connected topology (figure 1), characterized by high reliability, since if a dedicated communication channel fails, information can be transmitted along detour paths through intermediate nodes.
- A tree-like topology (figure 2), characterized by low reliability, since the failure of even one of the communication channels can lead to the dismemberment of the network into two isolated subnets.
- The ring topology (figure 3), like the tree topology, has low reliability, since the failure of any one link leads to a network failure. However, redundancy can improve the reliability of the ring topology by using multiple rings.
- The radial (star) topology (figure 4) has a fairly high reliability compared to other topologies, since the peripheral nodes operate independently of each other. Failure of the central node leads to the failure of the entire network. Therefore, it is necessary to apply the redundancy of this node.
If a node or communication channel fails, the system should automatically recover in a set (usually very short) time. In this case, one of the backup routes of data delivery from the sender to the recipient should be used. Redundancy of communication channels allows you to minimize delays in data transmission, while at the same time significantly increasing the values of the system's MTBF parameters.

Let's compare the reliability of the ring and radial topologies in terms of the operational availability factor.

3. Determination of the operational readiness coefficient of a TCN with a "star" structure
A TCN with a radial topology is operational if at least one peripheral node is running while the central node is running. If all nodes or the central node fail, the network is inoperative.

As an example of a TCN with a "star" structure, consider a network consisting of a central node and 2 peripheral nodes [5-7]. Then the coefficient of operational readiness is determined according to the main structural diagram of reliability by the expression:

$$K_{or\ s}(t) = \frac{2T_0}{T_v+2T_0} \cdot P_{cs}(t) \cdot [2 \cdot e^{-\lambda t} - e^{-2\lambda t}],$$

(2)

where $T_0 = \frac{1}{\lambda}$ - time to failure of a peripheral node; $T_v = \frac{1}{\mu}$ - average recovery time of a peripheral node; $P_{cs}(t)$ - likelihood of central site uptime; $\lambda$ - peripheral node failure rate; $\mu$ - peripheral node recovery rate.

Assuming that an exponential model of MTBF can be used for the central node, we will reduce expression (1) to the following form:

$$K_{or\ s}(t) = \frac{2T_0}{T_v+2T_0} \cdot e^{-\lambda_{cs} t} \cdot [2 \cdot e^{-\lambda t} - e^{-2\lambda t}],$$

(3)

where $\lambda_{cs}$ - central node failure rate.

Usually the central node is more reliable than the peripheral nodes, so we set $\lambda_{cs}=\lambda/2$.

The dependence $K_{or\ s}(t)$ for $\mu = 0.04$ and various values of $\lambda$ ($1.5 \times 10^{-5}$, $2.5 \times 10^{-5}$ и $5 \times 10^{-5}$) is plotted in figure 5.

4. Determination of the operational availability factor of a TCN with a ring topology
A TCN with a ring topology is operational if all nodes are operational, which corresponds to a sequential reliability model. If one of the nodes fails, the network is inoperative.

The operational readiness coefficient of the TCN with the "ring" structure is determined by the expression [1, 8-10]:

$$K_{or\ r}(t) = \frac{T_0}{T_v+T_0} \cdot e^{-n\lambda t},$$

(4)

where $n$ - number of nodes.

The dependence $K_{or\ r}(t)$ for $\lambda=5 \times 10^{-5}$, $\mu=0.04$ and the number of nodes $n = 2, 3, 4$ is shown in figure 6.
Figure 5. Ratio of operational availability of TCN with radial topology.

Figure 6. Ratio of operational availability of TCN with radial topology.

From the dependencies in figure 5 and figure 6 it follows that in order to achieve higher reliability, it is necessary to use a TCN with a "star" structure. For example, at \( t = 12000 \) hours, the operational availability factor of a TCN with a radial structure is 0.9, and for a TCN with a ring topology at \( n = 2, 3, 4 \), respectively, it is 0.7; 0.59; 0.5.

5. Conclusion
In this paper, the analysis of the operational readiness factors of TCN with radial and ring topologies and these structures is carried out. It is shown that a star-shaped TCN provides higher reliability compared to TCN with a ring topology at the exit of the peripheral node. However, in a TCN with a radial topology, the failure of the central node leads to a complete degradation of the entire system.

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