Stability Method of Connectivity Automated Calculation for Heterogeneous Telecommunication Network

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Abstract

The main principles of activity, which provide the ability to establish communication between consumers of the telecommunication network, include ensuring its stability, which is to maintain the functioning in case of failure of some facilities. Among the possible areas of activity in this direction, considering the variability of the modern natural and anthropogenic environment, the improvement of systems for collecting, processing and using metrological information on the sustainability of the network is considered promising. The article concentrates on the creation and study of the methods for calculating the connectivity of the path, taking into account the failures of the means of communication. The main parameters of the network stability have been studied. The main factors of stability of the communication means have been defined: reliability; selection of routes for laying and suspension, ensuring the safety of the cable communication lines; automatic inclusion of a reserve; maintenance procedures. Network reliability is studied in detail. The proposed technique allows automatically calculate the connectivity of a heterogeneous telecommunication network, which will allow real-time monitoring of network stability.

Keywords

Heterogeneous telecommunication network, reliability, stability, connectivity.

1. Introduction

Generally, heterogeneous telecommunication networks include networks, whose reliability characteristics change, for example, due to the changes in the load on the network or its elements, modification of the network structure, the presence of the network elements downtime, changes in the conditions of the network operation, etc.

These networks are networks with reconfiguration of their structure. Modifications in the network can occur both at constant and variable intervals; they can be deterministic or random, periodic and non-periodic. The structure of the network may change due to the changes in the functions, performed by the system, as well as in order to increase its functional stability.

The main issues of the heterogeneous telecommunication networks analysis are the development of the models and methods for calculating the characteristics of their functional stability, as well as managing the process of modifications in order to obtain the greatest functional stability of the network according to selected criteria.

Ensuring some standardized values of the readiness, reliability, maintainability and maintenance includes measures that characterize the stability of the telecommunication network and telecommunication facilities. The list of such measures is included in ITU Recommendation E.862 "Telecommunication Network Reliability Planning" and includes [1]:

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1. Availability performance.
2. Reliability performance.
3. Maintainability performance, which are characterized by the certain time intervals t_m.

To ensure the functional stability of the network, a methodology for automated calculation of telecommunications network connectivity has been developed.

2. Stability of a Heterogeneous Telecommunication Network

Dangerous events generate destabilizing factors (DF), which are characterized by the physical, chemical and biological activities or manifestations that are determined or expressed by the relevant parameters [2].

Network resilience consists of Robustness, Self-organization, Learning, Redundancy, Flexibility and Diversity, Rapidity, Scale.

Robustness refers to the network's ability to maintain its performance in the conditions of environmental shocks and fluctuations. It includes the ability to mitigate the risks and consequences of climate change in order to maintain the efficiency of the sector.

Self-organization means the ability of a network to rearrange its functions independently and processes in the conditions of external disturbances in order to resist, bounce back and adapt to its influences.

Learning means the ability of a sector to acquire or create knowledge, as well as to strengthen skills and abilities. It is closely linked to the processes of experimentation, discovery and innovation.

Redundancy refers to the extent to which functions, services and components in the sector are interchangeable; for example, in case of disturbance or degradation.

Flexibility and diversity relate to the sector's ability to take different actions with its determinants, while innovation and the use of opportunities may arise from the changes.

Rapidity is the speed with which gives access or activates assets to effectively achieve the goals of the sector, especially in the event of shocks.

Scale refers to the breadth of the assets that a network can access to effectively overcome, bounce back, or adapt to the effects of disturbances.

Resistance of the separate resources of a heterogeneous telecommunication network to action of destabilizing factors is provided on condition of the emergence of boundary condition prevention [3]:

$$S\left(\vec{r},t\right) \geq F\left(\vec{r},t\right), \tag{1}$$

where $S\left(\vec{r},t\right)$ is the value of the resistance criterion to the destabilizing factor (DF), $\vec{r}$ is the radius vector of the DF field point; t is time; $F\left(\vec{r},t\right)$ – DF value.

Network objects must comply with the principle of redundancy, which allows reconfiguration of the telecommunication network [4].

Using the redundancy of the communication lines due to the alternative technologies, for example, optical transmission technology over fiber-optic communication line (FOC) and in free space, high-frequency communication over power lines, radio-relay communication is proposed.

Network resources are n-dimensional stations and nodes, which are a set of the vertices of the graph of the telecommunication network $\upsilon_i \in V$, and the communication channels between them are described by a set of the edges $e_{ij} \in E$. The network topology is determined by the graph $G(V,E)$, described by the connectivity matrix [5]:

$$A = \left\| a_{ij} \right\|,\ i, j = \overline{1,n},\ a_{ij} = \begin{cases} 1, \forall e_{ij} \in E; \\ 0, \forall e_{ij} \notin E. \end{cases} \tag{2}$$

The stability of the network, which combines many individual resources, is determined under the following conditions [5]:

$$\left\{\begin{array}{l}\chi\left(G\right)\geq 2;\\ \lambda\left(G\right)\geq 2;\\ P_{ij}\left(t\right)\geq P_{ij}^{normalized};i\neq j;i,j=\overline{1,n}\end{array}\right\}, \quad (3)$$

where $\chi(G)$ is the number of the vertex connectivity (the smallest number of the vertices, the removal of which together with the incident edges leads to an incoherent or single-vertex graph); $\lambda(G)$ is the number of edge connectivity (the smallest number of the edges, the removal of which leads to an incoherent graph); $P_{ij}(t)$ is the probability of connectivity (the probability that the message from the node *i* to the node *j* will be transmitted in a time not exceeding *t*).

The ability to reconfigure the network is provided by increasing the vertex connectivity, edge connectivity, the probability of connectivity.

Four main factors determine the stability of the communications are reliability; selection of the routes for laying and suspension, ensuring the safety of the cable communication lines; automatic inclusion of a reserve; maintenance procedures [6, 7].

The reliability of the measures describes the time between failures t_r [8].

The stability of the cable line can be determined from the characteristics of the reliability of the cable and its operating conditions. The reasons for refusal are as follows [9]:

- vandalism (mainly in case of the underground cables with metal elements detected by metal detectors and overhead cables);
- hidden manufacturing defects;
- low-quality construction or installation work;
- design errors (incorrect choice of the cable type, inappropriate fittings, non-compliance with technical requirements of operating conditions).

Network failures and shutdowns should be automatically detected and neutralized by duplicating the most important nodes and stations and, if possible, by reconfiguration [8].

Maintenance and repair of the resources is carried out in accordance with the:

1. Rules of technical operation of the primary network of the Unified National Communication System Guideline 45-112-99 [10].
2. Rules of technical operation of the electrical installations of telecommunication enterprises of Ukraine (from 29.10.1996 № 232) [11, 12].
3. Rules of technical operation of power plants and networks Industry Guidance Document 34.20.507-2003 [8].

Maintenance and repair of the resources should include operational control of the technical condition of linear structures and the implementation of periodic, scheduled maintenance and current work for maintaining their efficiency and serviceability, damage prevention, detection and timely elimination.

3. Method of Automated Calculation Connectivity

On the basis of the conducted researches the developed technique is intended for the automated calculation of connectivity:

1. Collect the following data from the network:
   - The time during which the system is in working condition t_r.
   - The time interval from failure to its detection $t_{m_{01}}=[t_{m_0},t_{m_1})$.
   - Maintenance time interval $t_{m_{12}}=[t_{m_1},t_{m_2})$.
   - Repair time interval $t_{m_{23}}=[t_{m_2},t_{m_3}]$.
2. Calculation the total recovery time in the general case, which is:

$$t_m=t_{m_{01}}+t_{m_{12}}+t_{m_{23}}. \quad (4)$$

3. When assessing the reliability of the telecommunication channel, its resistance to threats is determined by the readiness factor of the channel, which is calculated by the formula:

$$k = \frac{t_r}{t_r + t_m}. \quad (5)$$

where t_m is recovery time interval, t_r is the time during which the system is in working condition.

Failure of the roads connectivity leads to the failure of telecommunications. The connectivity μ_{ij}^{l} of the k_{ij}^{l} l^{th} path from the list of all chains μ_{ij} is the common probability of good condition of all edges and vertices that form this chain.

4. Calculate the connectivity μ_{ij}^{l} of the k_{ij}^{l} l^{th} path

$$k_{ij}^{l} = \prod_{\forall a \in \mu_{ij}^{l}} k_a , \quad (6)$$

where k_a is the coefficient of readiness of the a^{th} element of the sequence of the edges and vertices belonging to the path μ_{ij}^{l}.

5. Calculate the probability of the path k_{ij} connectivity between nodes υ_i and υ_j (the probability of a good state of at least one circuit of all possible circuits)

$$k_{ij} = k_{ij}^{\max} = 1 - \prod_{\forall \mu_{ij}^{l} \in \mu_{ij}} \left(1 - k_{ij}^{l}\right). \quad (7)$$

The coefficient of the readiness of a network fragment, created by parallel-connected means of telecommunications (Fig. 2) is determined by the formula

$$k_{\Sigma} = 1 - \left[\left(1-k_1\right)\times\left(1-k_2\right)\times\ldots\times\left(1-k_i\right)\times\ldots\times\left(1-k_n\right)\right] = 1 - \prod_{i=1}^{n}\left(1-k_i\right), \quad (8)$$

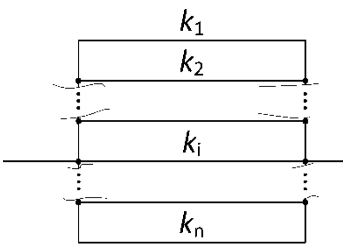

Figure 1: *Network fragment, created by parallel-connected means of telecommunications*

6. In real conditions, chains are often interdependent, i.e. have common edges and vertices. The probability of connectivity, calculated by the previous formula, has higher value. The true value will be obtained if, in the calculations after opening the brackets, all members with exponents greater than one are replaced by unit, which corresponds to the exclusion of the event of multiple consideration of the readiness factor of one edge or one vertex. This action is denoted by the symbol E and is called absorption. The formula for calculating connectivity takes the following form.

$$k_{ij} = E\left\{k_{ij}^{\max} = 1 - \prod_{\forall \mu_{ij}^{l} \in \mu_{ij}} \left(1 - k_{ij}^{l}\right)\right\}. \quad (9)$$

Fig. 1 presents a block diagram of the method of automated calculation of the network connectivity:

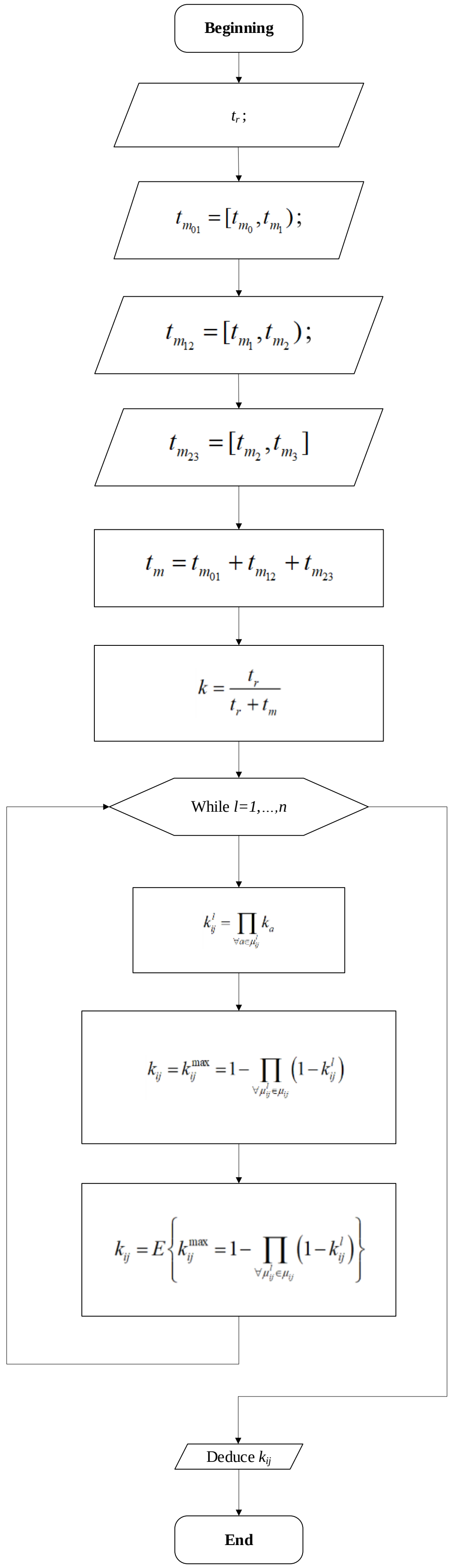

Figure 2: *Algorithm for calculating the connectivity of the path*

4. Conclusions

Thus, the stability of a heterogeneous telecommunication network has been studied in the paper; a method of its constant control due to the automated calculation of its connectivity, taking into account the failures of communications has been proposed.

Developments on monitoring the stability of the heterogeneous telecommunications network and its protection against hazards can be considered for use in other network structures: electric and sewerage networks, water supply systems, gas supply, pipeline transport of gas, oil, petroleum products supply systems.

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