



ANALYSIS OF BASIC TOPOLOGIES AND TYPICAL STRUCTURES OF TELECOMMUNICATION NETWORKS

Saydiakhat S. Parsiyev

Professor of the Department of Information Technology at the University of Public Security of the Republic of Uzbekistan,
Doctor of Technical Sciences (DSc), Associate Professor, Uzbekistan

Abstract

This article analyzes the topology of telecommunication networks (TN) with various structures and reveals that, despite the numerous ways to connect nodes, network construction is based on three main (basic) topologies: bus, ring, and star. It is shown that in telecommunication networks, radial, ring, and radial-ring structures are among the most frequently used typical structures. The penalty function method determines the optimal TN structure based on the criterion of overall network reduced costs. Additionally, when choosing the most preferred basic typical structure for building telecommunication networks, the relative efficiency coefficient is proposed as an indicator.

Keywords

Telecommunication network, network structure, network topology, penalty function, optimal structure, efficiency coefficient.

INTRODUCTION

A modern telecommunication network (TN) is an object of high structural complexity that can be represented as a complex graph consisting of numerous switching nodes. The theory of constructing such a structure is not yet fully developed and is still under study. In a telecommunication network, the network topology is understood as the configuration graph, where the end nodes are the network vertices (e.g., computers) and communication equipment (e.g., routers), while the communication channels between the vertices are the edges. The structure TN represents the mapping and description of physical and logical connections between its elements. The topology of a TN is related to the location of objects, their appearance, and is part of the overall network structure, reflecting the physical, territorial, and spatial connections between its elements. In the problem of creating and developing a TN, important issues include the study and optimization of technical-economic and structural-network parameters, as well as the network's flow characteristics. Correctly addressing these important issues allows for the design and development of a TN to achieve minimal network characteristics and the desired technical effect.

Modern telecommunication networks are an important systemic component of the global information infrastructure (GII) at both national and international levels. Telecommunication networks are entrusted with key functions in organizing informational interactions between GII elements by creating a high-speed transport medium. The constant increase in requirements for the efficiency of telecommunication networks, largely accompanied by the expansion of capabilities to support Quality of Service (QoS), significantly influences the design processes of such networks. It is at the design stage that the necessary reserve of network resources is laid, which should subsequently be optimally distributed and, if necessary, increased during the operation of telecommunication networks.

It is important to note that the design process of telecommunication networks should not be viewed as an event associated exclusively with the synthesis of a network "from scratch." Generally, this term is interpreted much more broadly and covers

tasks such as replanning, restructuring existing TN, or creating overlay networks in the interests of individual firms and companies based on the existing telecommunication infrastructure of a particular service provider. When solving TN design tasks, it is necessary to take into account a multitude of contradictory requirements, ranging from maximizing the number of users covered by communication services, supporting a specified level of service quality, to minimizing the total cost of the created network.

In this regard, it is important to leverage the capabilities of a systematic approach both at the stage of formalizing design tasks and in ensuring their effective resolution.

METHODS

The penalty function method (PFM) [5], a powerful computational tool in optimization theory, was chosen as the method for determining the basic topologies of TN. The penalty function method is convenient because the structure of constraints, their nonlinearity or linearity, smoothness or non-smoothness, does not play a crucial role in solving the minimization problem. Furthermore, PFM does not require the initial point to belong to the feasible region. Applying this method allows for the calculation of probabilistic-temporal characteristics, determination of topology, distribution of information flows, selection of bandwidth, calculation of overall network reduced costs, and determination of the optimal TN structure. There are numerous ways to connect nodes in a TN, but all are based on three main (basic) topologies: bus, star, and ring [1, 4, 2].

A bus-type telecommunication network is a network topology in which all terminals are connected to a transmission medium that serves as a data transmission bus [1, 2] (Fig. 1).

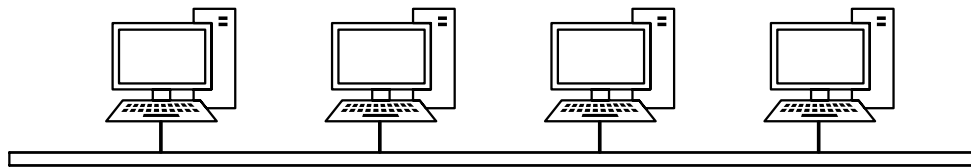


Fig. 1. Basic Topology of a Bus-type Telecommunication Network

A star-type telecommunication network is a topological scheme that practically resembles a “star” (Fig. 2). In this network, each remote node is connected to a central switch, node station, or channel hub. A network with a star topology allows for branching traffic for local users and redistributing it among remote users [2].

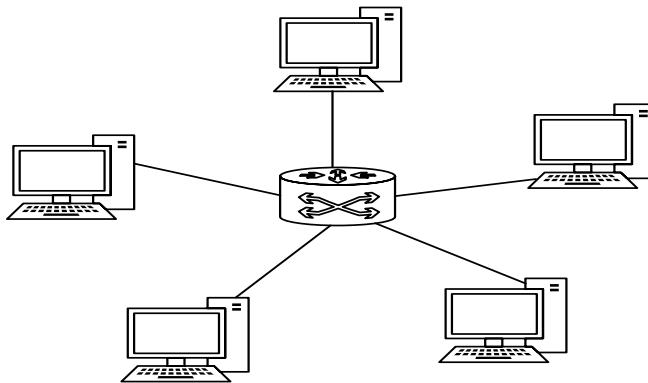


Fig. 2. Basic Topology of a Star-type Data Transmission Network

A ring-type telecommunication network is a network topology where the terminals are interconnected in a circular configuration [1, 2].

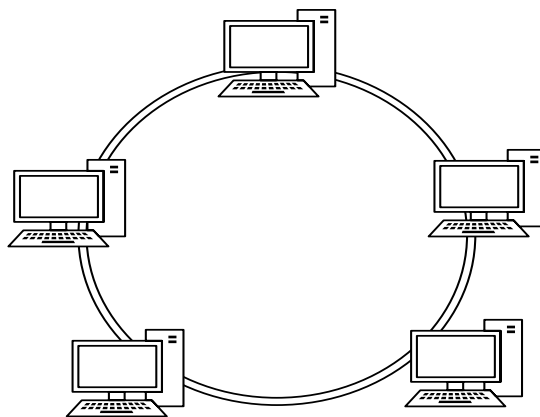


Fig. 3. Basic Topology of a Ring-type Data Transmission Network

Some of the most frequently used telecommunication network structures are typical radial, ring, and radial-ring structures. A radial structure is a single-connected structure with N edges. This structure has a central vertex (node) $a_{\text{св}}$, through which all possible correspondent node pairs are formed. In the radial structure, there are simple linear structures consisting of multiple graph edges that lie between the central vertex $a_{\text{св}}$ and other nodes a_i from the set of graph vertices $A = \{a_i; i = \overline{1, N}\}$ [10] (Fig. 5).

The ring structure is a double-connected structure with N edges, where communication nodes are connected by edges in a ring. A feature of the ring structure is that there is only one path between any correspondent pair of nodes [10] (Fig. 6).

The radial-ring structure is built based on a mixed radial and ring structure with a nodal basis $A = \{a_n; n = \overline{1, N}\} \cup a_{\text{св}}$ [9, 11] (Fig. 7).

To select the most preferred basic typical structure for constructing a high-speed data transmission network based on fiber-optic communication lines, the relative efficiency coefficient is used as an indicator [9, 11].

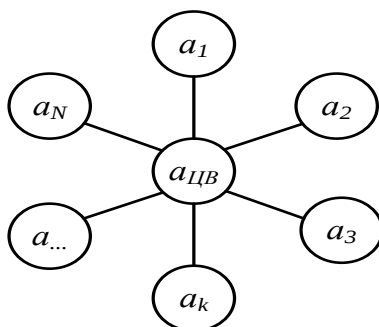


Fig. 5. Basic Structure of a Radial Network

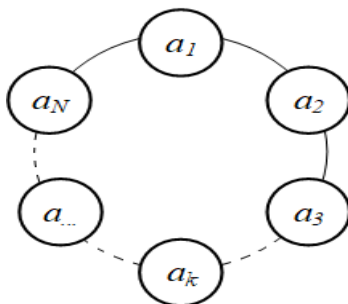


Fig. 6. Basic Structure of a Ring Network

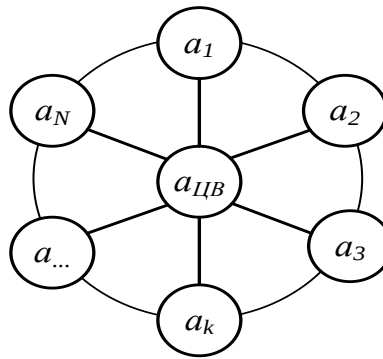


Fig. 7. Basic Structure of a Radial-Ring Network

Table 1 provides a comparison of telecommunication network topologies: bus, ring, and star [1, 3, 4].

Table 1.

Comparison of basic telecommunication network topologies

№	Topology	Advantages	Disadvantages
1	2	3	4
1	Bus	Simplicity of implementation and setup. Lower communication line usage. Relatively low cost.	Relatively low network reliability. Low network bandwidth. Many devices use common communication channels, leading to signal collisions. Network extension difficulties.
2	Ring	Ability to build large networks. No signal collisions, hence resistant to overloads.	Long signal transmission time. Failure of one communication line or one node disrupts the network. Adding additional nodes requires stopping the entire network.
3	Star	Network reliability, as a communication line failure affects only one node. Centralized management and control.	Central node failure disrupts the entire network. Higher communication line usage compared to bus and ring topologies.

When solving TC design tasks at the levels of structural and functional synthesis, heuristic approaches based more on engineering intuition than on theoretically justified solutions often find and continue to find application. The structural complexity of TC and its individual parts, the large amount and diversity of initial data, and the need to forecast these data – all this determines the high level of theoretical complexity in solving network construction and development tasks, especially those concerning its dynamics. Therefore, methods are needed to create a network calculation apparatus under conditions of its dynamic development.

RESULTS

The spectrum of possible topologies is characterized by a set of basic structures, including "radial network," "ring communication network," and "star".

For the radial structure case, the relative efficiency coefficient $K_{ef.RN}$ is determined as follows:

$$K_{ef.RN}(N) = 8,91K_{CC}/N, \quad (1)$$

where N is the number of edges; K_{CC} is the curvature correction coefficient of the edges when laying communication lines. The relative efficiency coefficient $K_{ef.KC}$ for the ring structure is determined as follows:

$$K_{ef.RC}(N) = 0,11N/K_{CC}. \quad (2)$$

In [9,10], the justification for choosing the radial-ring structure of the network depending on the number of edges (N) and the curvature correction coefficient of the edges (KCC) is proposed to be based on the geometric and harmonic mean relative efficiency coefficients. For the radial-ring structure, the geometric mean relative efficiency coefficient $K_{ef.RRS}$ is determined as follows:

$$K_{ef.RRS}(N) = \sqrt{K_{ef.RadS}(N) \cdot K_{ef.RinS}(N)}. \quad (3)$$

The harmonic mean relative efficiency coefficient $K_{ef.RS}$ for the radial-ring structure is determined as follows:

$$K_{ef.RRS}(N) = \frac{2 \cdot K_{ef.RadS}(N) \cdot K_{ef.RinS}(N)}{K_{ef.RS}(N) + K_{ef.RinS}(N)}. \quad (4)$$

From equations (1) to (4), the relative efficiency coefficient can be determined considering different values of the curvature correction coefficient KCC and the number of edges N. Based on a comparative analysis, the most efficient option for building a telecommunication network can be determined.

Now, using PFM, let's determine the optimal TN structure based on the criterion of total network reduced costs, considering the number of hierarchy levels of TN. The task of determining the optimal TC structure using the penalty function method (PFM) is a procedure for solving a complex optimization task focused on applying design and forecasting tasks of technical and economic indicators of telecommunication networks with a multi-level structure. The obtained results are shown in Figure 8.

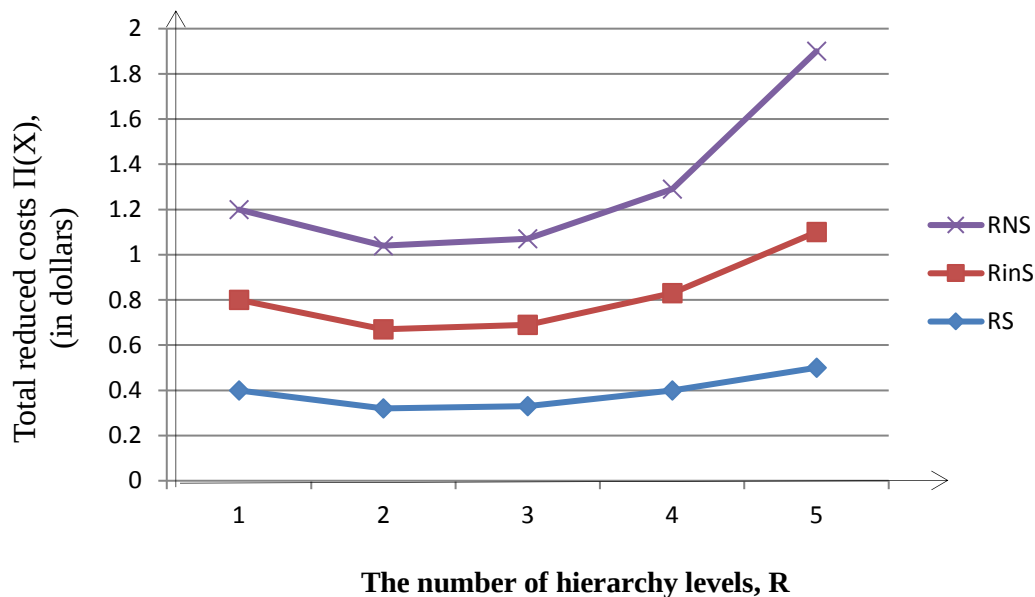


Figure 8. Dependence of the cost characteristics of a multi-level telecommunication network on the values of the curvature correction coefficient

Note: RNS - Radial-nodal structure; RinS - Ring structure; RS - Radial structure.

In practice, when constructing large-scale networks, combined network topologies are used, which is due to the technical capabilities of organizations' communication lines and the locations of network nodes.

When designing such a network, the overall length of network channels is reduced, node equipment and network channels are used effectively, network management procedures are simplified, and certain resource savings are achieved, etc. According to sources [1,2], combined topologies have the following advantages over other networks:

- Reduction in the overall length of network channels due to the multiple use of connection links.
- Effective use of node equipment and communication channels.
- Maximum possible load balancing at lower hierarchy levels.
- Simplified network management procedures.
- Resource savings in the network.

Typically, at the end of the system design phase, a set of "network components" is obtained: switching nodes, communication channels, the number of concentrators, and switching centers with known characteristics. One could say that the design is complete at this stage.

However, for a network designer, this is not enough. They must find the best arrangement of components that meets the requirements for network traffic. Usually, it should be an economical option that meets certain network efficiency criteria (e.g., ensuring minimal cost and delay in the network, given performance, throughput, and reliability). This stage of the design process can be called network optimization based on economic criteria.

CONCLUSION

Thus, an important area of research in telecommunications networks today is to consider them as multi-level systems with a hierarchical structure. Currently, the mathematical theory of such hierarchical systems is not well developed. Therefore, further scientific research should be dedicated to the development of models, methods, and algorithms for optimizing TN to demonstrate their operational efficiency. The construction and creation of TN, their development and research involve solving a wide range of network analysis and synthesis tasks. The main content of this is defined by the design methodology, where a network's topological structure is formed to meet the requirements for its characteristics, technical means are selected, and software is developed. Additionally, it involves determining which control devices and management protocols will be chosen for the processes occurring during the operation of the TN.

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