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ANALYSIS OF FACTORS AFFECTING THE RELIABILITY OF TELECOMMUNICATION INFRASTRUCTURES

M.M.U. MURADOV

Tashkent University of Information Technologies named after Muhammad al-Khwarizmi
(Tashkent, Uzbakiston)

E-mail: muradov.muhammad1414@gmail.com

Аннотация. Данная диссертация направлена на проведение комплексного анализа внешних, технологических, человеческих факторов и факторов безопасности, влияющих на надежность телекоммуникационных инфраструктур, а также на обоснование практических методов повышения надежности на основе современных технологий и стандартов.

Abstract. This thesis aims to conduct a comprehensive analysis of external, technological, human, and security factors affecting the reliability of telecommunications infrastructures, as well as to substantiate practical methods for increasing reliability based on modern technologies and standards.

Introduction

In the modern information society, telecommunications infrastructure has become a key component of the economy, social life, and national security. As a result of the rapid development of digital transformation processes, the introduction of 5G technologies, and the widespread use of cloud computing and Internet of Things (IoT) systems, the demand for telecommunications networks is growing at an unprecedented rate. Therefore, the issue of the reliability of these networks increases its relevance and importance.

Research conducted worldwide shows that disruptions in telecommunications networks cause economic damage amounting to billions of dollars annually on a global scale. In particular, according to the International Telecommunication Union (ITU), network outages in developing countries average 50–200 hours per year, which is a serious obstacle to the development of the digital economy [1, 2]. In Uzbekistan, within the framework of the digital economy development strategy, ensuring the stability of telecommunications infrastructure is defined as a national priority.

Reliability is the ability of a system to fully perform its functions under given conditions over a specified period of time. In the telecommunications industry, reliability is measured by three main parameters: (1) availability - the ratio of the system's readiness for operation, usually expressed as 99.999% (“five-nine”); (2) MTBF (Mean Time Between Failures) - the average time between failures, indicating the level of system stability; (3) MTTR (Mean Time To Repair) - recovery time, the average time until the malfunction is eliminated. These parameters are the primary criteria for the design and operation of the system [2].

The main part

External and natural factors. Telecommunications infrastructure is strongly influenced by the external environment. Climatic conditions-high temperatures, humidity, and freezing-significantly reduce the service life of optical cables and active devices [3]. Research shows that a 10°C increase in temperature doubles the probability of electronic components failing (Arrhenius model). Due to strong winds and thunderstorms, damage to antenna structures and disruptions in satellite communication systems were observed. Natural disasters, such as earthquakes, floods, and mudflows, pose a risk of simultaneously destroying large-scale infrastructure-the 2011 Japanese earthquake disrupted 1.5 million access points. Electromagnetic interference (EMI) is a serious problem, especially in networks near industrial zones and military training grounds. Power supply disruptions remain one of the main factors affecting reliability in the Central Asian region: the reserve capacity of UPS (uninterruptible power supplies) and diesel generators is limited to 4–72 hours, which cannot protect the system during long-term power outages [3].

Technical and technological factors. Device wear and tear is one of the most common technical factors. Capacitors, transformers, and optical connectors sharply increase the probability of failure after a certain period of time; this process is described by the “bath curve” model. Software errors are an increasingly important problem in modern IP networks, with 35-40% of network device interruptions occurring specifically as a result of software malfunctions [4]. While the complexity of the network topology allows for increased redundancy, it also complicates configuration errors and fault diagnostics. Bandwidth-related issues can lead to service quality deterioration and network inefficiency during periods of sharp traffic congestion.

Human factor and cybersecurity. According to statistics, 30-40% of network outages are caused by human error: incorrect configuration, violations of maintenance regulations, and the failure to conduct preventive maintenance. Cyberattacks, specifically DDoS (Distributed Denial of Service) attacks, can create an excessive load on the system and completely suspend service for real users. Ransomware and botnet viruses, on the other hand, disable network management systems and cause significant material and moral damage. Individuals-cutting cable lines, breaking cabinets, and damaging cabinets-are a major problem, especially in open areas that cannot be controlled. The quality of maintenance is also crucial: a lack of qualified personnel, violations in maintenance schedules, and a shortage of spare parts increase the MTTR and reduce the network availability ratio.

The impact of modern technologies: 5G, NFV and SDN. Fifth-generation communication technology (5G) requires ultra-low latency (less than 1 ms) and high reliability standards (99.9999% - "six-nine"), which places a new technological burden on the infrastructure. NFV (Network Functions Virtualization) implements network functions in a software-independent form, facilitating rapid recovery and backup, but hypervisor-level vulnerabilities create new threats. SDN (Software-Defined Networking) allows for the dynamic modification of network configurations, load balancing, and automatic fault redirection through centralized control. However, the fact that one point of the SDN controller can be critical for failure is indicated as its main disadvantage. These technologies, when applied with the correct architecture and backup schemes, allow for a significant increase in overall network reliability.

Methods for increasing reliability. The main methods for increasing reliability include several directions. First, system backup-preventing outages through primary and backup devices, parallel channels, and geographically separated data centers. Active-Active and Active-Standby schemes allow for maintaining network readiness above 99.99%. Secondly, dynamic load distribution-balancing traffic flows in several directions-reduces the problem of bottlenecks. Third, automatic monitoring and intelligent diagnostics-predictive maintenance systems based on AI and ML algorithms-allow for the detection of malfunctions before they occur. Research confirms that predictive maintenance can reduce the MTTR by 30-60%. Fourth, regular staff training and automatic network configuration verification systems help reduce errors caused by the human factor.

International standards and regulatory requirements. The main international documents regulating the reliability of telecommunications infrastructures are: ITU-T G.821 and G.826 standards establish norms regarding digital channel interruptions and requirements of the MTBF/MTTR; ITU-T Y.1541 regulates QoS parameters for IP networks, including latency, packet loss, and availability coefficients; ISO/IEC 27001 defines requirements for information security management systems, including issues of network resilience. The ETSI EN 301 908 standard establishes reliability requirements for 5G networks, while TIA-942 defines Tier I-IV levels of data center infrastructure (readiness from 99.671% to 99.995%) [5-8].

Conclusion

The analysis showed that the factors affecting the reliability of telecommunications infrastructures are divided into four main groups by their nature: external and natural factors, technical and technological factors, the human factor, and cybersecurity issues. These factors often have a mutually reinforcing effect - malfunctions - creating a particularly dangerous situation. Nevertheless, modern technologies - 5G, NFV and SDN - can significantly increase reliability when properly applied.

Based on the conducted research, the following practical proposals were developed:

1. Equipping critical nodes with climate control systems when designing network infrastructure, taking into account the climatic and geographical characteristics of the region.
2. Implementation of a forecast maintenance system based on MTBF/MTTR indicators and the creation of a centralized real-time monitoring system for this data.
3. Creation of virtualized backup systems based on NFV and SDN technologies.
4. Development of a system for predictive management and monitoring of power supply sources based on artificial intelligence to minimize power supply interruptions in telecommunications infrastructures.

As further research in this direction, it is recommended to consider issues such as the creation of an empirical database of MTBF/MTTR in the conditions of the Republic of Uzbekistan and the development of models and algorithms that increase reliability for the national telecommunications network.

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