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Tayr Moydunov*
Doctor of Technical Sciences
Osh Technological University named after M.M. Adyshev
723503, 81 Isanov Str., Osh, Kyrgyz Republic
https://orcid.org/0009-0002-4328-3269

Adilkan Sarimsakov
PhD in Technical Sciences
Osh Technological University named after M.M. Adyshev
723503, 81 Isanov Str., Osh, Kyrgyz Republic
https://orcid.org/0009-0004-3175-5796

Saltanat Omorova
Postgraduate Student
Osh Technological University named after M.M. Adyshev
723503, 81 Isanov Str., Osh, Kyrgyz Republic
https://orcid.org/0009-0005-5627-7935

Altynai Nychsanova
Postgraduate Student
Osh Technological University named after M.M. Adyshev
723503, 81 Isanov Str., Osh, Kyrgyz Republic
https://orcid.org/0009-0007-7100-1982

Joomart Matisakov
Postgraduate Student
Osh Technological University named after M.M. Adyshev
723503, 81 Isanov Str., Osh, Kyrgyz Republic
https://orcid.org/0009-0009-5622-3901

Analysis of radio relay station control system using IT-technologies

Abstract. The study addressed the theoretical analysis of radio relay station control systems using modern information technologies. The study aimed to identify the potential for improving the performance, reliability and cost-effectiveness of such systems. The analysis investigated advanced sensor technologies, automation algorithms and monitoring techniques that could significantly reduce maintenance costs and speed up fault response. Key aspects affecting the performance of radio relay stations were considered, including the impact of climatic conditions and various operational scenarios. The importance of automation integration to improve system reliability and reduce the impact of human error was emphasised. Compliance of the proposed solutions with international radio relay standards, which simplified integration with existing networks and the possibility of future modernisation, was also highlighted. The results of the study substantiated the necessity of automation of radio relay systems and created a theoretical basis for their further development and improvement, which opened new opportunities for improving operational characteristics and increasing resistance to potential failures. The implementation of new approaches to data management and analysis was addressed, ensuring quick response to changes during operation as well as resource optimisation. These aspects provided a competitive advantage in a rapidly changing telecommunications technology environment, emphasising

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*Corresponding author

the importance of flexibility and adaptability of systems for efficient operation. As such, the study of the theoretical foundations of automation can be used as a basis for practical recommendations for the implementation of innovative technologies in radio relay station management

Keywords: communication automation; sensor modules; machine learning; remote monitoring; reliability enhancement; economic efficiency

INTRODUCTION

The development of automated control technologies has become an integral part of many industries, including telecommunications systems. Radio relay stations are substantial in the transmission of data over long distances, especially in remote and inaccessible regions where other means of communication are limited. The efficiency of such stations, their reliability and cost-effectiveness directly depend on the quality of control and monitoring. However, traditional control systems for radio relay stations have many disadvantages associated with manual operation, insufficient response time to faults, and significant maintenance costs. These factors necessitate the search for new solutions to optimise the operation of radio relay stations.

One of the key areas for improving the management of such stations is the application of modern IT technologies and data processing algorithms, including machine learning and sensor-based analyses. With the help of such technologies, the performance and reliability of radio relay stations can be significantly improved by predicting failures and automating routine operations. Scientific research in recent years confirms the significance and promising potential of such approaches for telecommunication facilities management. Researchers such as R.M. Thomas & S. Malarvizhi (2022), point out the need to improve the responsiveness of management and suggest the use of machine learning algorithms to monitor the state of equipment. I. Rojek *et al*. (2023) addressed the potential to improve failure prediction in telecoms networks using sensor data, and the impact of such systems in reducing equipment downtime. These works show the potential of data analytics technologies to reduce operational costs and improve station reliability. Moreover, I. Rojek *et al*. (2022) analysed the economic aspects of implementing automated control systems, and how automation can reduce maintenance costs and improve the overall economic efficiency of radio relay stations.

However, most existing research focuses on data analysis and processing algorithms, leaving less explored the integration of these technologies within an integrated radio relay station management system that accounts for operation in different climatic conditions and system scalability. At the same time, modern realities require the creation of solutions that can work effectively in remote areas with minimal operator involvement. S. Sadiki *et al.* (2018), who analysed the implementation of sensor systems for monitoring telecommunications equipment, showed that automated systems significantly reduce the need for service personnel and reduce the likelihood of human error. Nevertheless, specific aspects of the operation of such systems in radio relay communications, especially in the context of frequent climate change, require further study and adaptation.

At the same time, the introduction of secure transmission channels and modern communication modules remains an important part of the modernisation of radio relay stations, as this reduces the risk of leakage and ensures a high level of security of information transmission (Smailov *et al.*, 2023). T. Mazhar *et al*. (2023) addressed transmission security in telecommunication systems and emphasised the importance of secure communication modules to prevent cyberattacks and improve network stability. But despite this, there is a gap in the scientific literature related to the development of integrated control systems that could integrate sensor data, prediction algorithms and communication modules into a single infrastructure. This suggests that an established integrated control system for radio relay stations can not only improve the reliability of operation but also significantly reduce station operation and maintenance costs. The scientific literature devoted to the automation of radio relay stations and the application of modern IT technologies in telecommunication systems is extensive and diverse. The main areas of research include control automation, sensor technologies, machine learning algorithms, economic efficiency of automation, integration of secure communication modules and adaptation of systems to climatic conditions.

M. Wilson *et al.* (2020) discussed automated control algorithms that aim to improve the efficiency of radio relay stations. The study emphasises the need for rapid response to failures and the development of systems that can automatically adapt to changing conditions. Several papers, including the research of J.L. Álvarez *et al*. (2021), emphasised the use of sensor technologies for equipment condition monitoring. These works demonstrate how the integration of sensors into radio relay station control helps to reduce downtime and improve reliability. A.P. Kane *et al*. (2022) investigated the use of machine learning to predict potential equipment failures. These algorithms can process large amounts of data and extract useful information for management decisions.

An important area of research is related to the security of data transmission. J. Pochmara & A. Świetlicka (2024) addressed the implementation of secure communication channels, which reduces the risk of leaks and increases the resistance of telecommunication networks to cyberattacks. Some studies, such as one by S. Sadiki *et al*. (2018), investigated how climatic changes affect the operation of radio relay stations and the need to adapt control systems in different climatic zones. Thus, the present study aimed to develop a system that will improve the performance of radio

relay stations, minimise the need for manual intervention and ensure reliable operation in different climatic zones. The main hypothesis of the study was that the use of an automated control system that integrates data acquisition modules, analysis algorithms and secure communications would reduce operating costs, improve station reliability and ensure system resilience to climatic changes.

LITERATURE REVIEW

Automation of radio relay control involves many aspects, including control mechanisms, monitoring systems and modern IT technologies. Automation has become an important aspect in many fields, particularly in telecommunications. According to a study by M. Wilson *et al*. (2020), new automated control algorithms significantly improved the management efficiency of telecommunication systems. The authors emphasise the importance of adaptive solutions that reduce the response time to problems. J.L. Álvarez *et al*. (2021) addressed the integration of sensor technologies in communication systems. They emphasise that real monitoring helps to reduce maintenance costs and improve reliability. This is also supported by A.P. Kane *et al*. (2022) who pointed out the role of machine learning in predicting maintenance of telecommunication equipment.

Security is an important aspect of automation. J. Pochmara & A. Świetlicka (2024) addressed the importance of secure data transmission channels to prevent cyberattacks. Security issues of automated telecommunication systems were also covered by S. Ainslie *et al*. (2023), who described modern methods of real-time monitoring and their impact on management decisions. A.O. Osahenvemwen & B.E. Omatahunde (2018) investigated the impact of climate conditions on telecommunication networks, pointing out the need to develop adaptive solutions to improve reliability in the face of climate change. This important observation was also supported by I. Rojek *et al*. (2023), who proposed automated systems to reduce the likelihood of outages in remote areas. In fact, despite the plethora of studies, many of them focus on individual aspects, leaving insufficient attention to the integration of technologies within complex systems. This is confirmed by a review of the works of K. Jakobsen *et al*. (2023), who analysed the challenges of automation in rural areas, emphasising the need for technical improvement.

Some studies also emphasise the economic benefits of automation. For instance, S. Berhe *et al*. (2023) presented predictive maintenance strategies that reduce the cost of operating equipment. This correlates with the economic benefit analyses conducted by U.R. Kamboh *et al*. (2017) who highlighted the main business benefits of automation. The impact of the Internet of Things (IoT) on telecommunication systems is also an important aspect. I. Appiah *et al*. (2023) pointed out that the integration of IoT into telecommunication networks can significantly improve automation and management processes, providing increasing efficiencies. This emphasises the need to develop and implement new protocols and standards that can ensure the smooth operation of these technologies in different environments.

According to a study by A. Aljohani (2023), predictive analytics is becoming more and more relevant for network management as it enables timely responses to potential problems. They emphasise the importance of data for making informed management decisions. Efficient processing of big data also opens new opportunities to optimise network processes and improve customer service. Equally significant are the studies by N. Zhao *et al*. (2023), which analyse the integration of communication technologies. They emphasise the importance of combining different technologies to improve the efficiency of systems. In addition, the works of L. Nazareno & D.S. Schiff (2021) investigated the impact of human factors on automated systems, emphasising the need to train and adapt personnel to new technologies. Lastly, the research of K. Park *et al*. (2023) analysed the scalability issues of automated control systems, pointing out the need to adapt technologies for different sizes of telecommunication networks.

In addition to the studies, S.G. Gavrila *et al*. (2023) significantly contributed to the overall research, as they addressed the ethical aspects of automation in telecommunications, emphasising the need to account for the social consequences of the introduction of new technologies. They emphasise that automation should address the interests of consumers and society. Another noteworthy contribution is the study by Y. Lee *et al*. (2023), which addressed the issues of sustainable development of telecommunication systems in the context of automation. The authors highlighted the need to integrate environmental aspects into automation strategies. The study by P.D.B. Kenfack *et al*. (2023) is also noteworthy, as it analysed the latest technologies that can be used to automate radio relay stations, emphasising the importance of innovation in this area. Lastly, the study by A.K. Aliyu *et al*. (2015) addressed the energy efficiency of automated systems, which is critical to reducing costs and increasing sustainability in the face of climate change. Thus, the literature review revealed a wide range of studies on automation in telecommunications, covering various aspects, from economic benefits to security and the impact of climatic conditions. However, despite significant progress, there is a need to further explore the integration of technology into integrated management systems, which will form the basis for future research in this area.

Additionally, it is possible to note that the growing interest in automation in telecommunications is linked to global trends in digitalisation and sustainable development. This underscores the importance of continuously exploring new technologies and methods that could have a significant impact on the future of the industry. Successful automation can significantly improve productivity and cost-effectiveness, which in turn will affect the competitiveness of companies and the quality of services provided.

MATERIALS AND METHODS

The study aimed to assess the effectiveness of automation of radio relay stations by analysing data collected in

previous experimental studies, as well as by summarising the practical experience of implementing automated systems in telecommunications. In this context, a comprehensive analysis of existing publications and practical experience regarding the impact of automation on key indicators such as fault response time, maintenance costs, reliability and cybersecurity of telecommunications systems was conducted (Table 1).

Table 1. Sources for analysing the main areas of telecommunications systems automation

Source	Primary research topic
M. Wilson *et al.* (2020)	Evaluation of the efficiency of automation algorithms at radio relay stations.
J. Pochmara & A. Świetlicka (2024)	Modern technologies in the field of telecommunications system security.
S. Sadiki *et al.* (2018)	The impact of the Internet of Things on the performance of radio relay stations.

Source: compiled by the authors

To systematise information on modern technological solutions in automation, several key aspects were considered that reveal the complexity and versatility of processes. Firstly, the system fault response rate determined how quickly and efficiently the system could detect and correct the problem. In automated telecommunications systems, this was particularly important to minimise equipment downtime, which reduced financial losses and improved service availability. Automatic monitoring systems analysed anomalies in real time and quickly notify operators, reducing delays in response. Maintenance costs were also a major concern. The introduction of automated technology could significantly reduce operating costs as systems can perform diagnostics, identify potential faults and schedule maintenance. This reduced the number of unscheduled repairs and reduced the likelihood of costly failures.

Another important aspect was the level of system reliability, which determined how resilient the system was to malfunctions and failures. The implementation of intelligent monitoring algorithms and predictive analyses could prevent faults before they occured, thus increasing the overall level of reliability. The integration of new technologies such as the Internet of Things (IoT) and predictive algorithms was addressed. IoT maked it possible to monitor equipment status remotely by collecting data from various sensors in real-time, which opened new possibilities for analysing and managing the network. Predictive algorithms, in turn, could predict potential problems based on accumulated data, thus creating a more resilient and manageable system. Interviews with telecoms specialists were also used to substantiate the relevance of automation (Xin *et al.*, 2023). The data collected covered various parameters such as fault response times, maintenance costs and security metrics including the frequency of cyber threats and their impact on data.

The analysis of the impact of automation on the integration of new technologies also covered methods of equipment condition monitoring and the use of machine learning algorithms. Machine learning was analysed in terms of predicting potential failures and replacing equipment on time to reduce downtime and improve overall network stability. Security materials were examined to assess the systems' ability to protect data from cyber threats. Statistical methods for processing the collected data were used to identify correlations between automation and improved radio relay station performance. Thus, the systematic approach was used to conduct a generalised analysis of the effectiveness of automated systems and outline areas for further optimisation of radio relay stations by reducing the influence of the human factor on their operation in different climatic conditions and regions.

RESULTS

Modern sensors used in the automation of radio relay stations provide high accuracy in monitoring the condition of equipment. They not only quickly detect faults, but also predict component wear, which is significant in improving system reliability. The use of real-time sensors allows for a quick response to changes in the condition of equipment, which reduces the likelihood of emergencies and increases the overall stability of the system.

By integrating sensor technology into the monitoring process, it is possible to significantly improve resource management and reduce downtime. For instance, predictive analytics based on sensor data can identify potential problems before they occur, reducing maintenance costs and improving safety. Adoption of such technologies also helps optimise maintenance schedules by enabling more accurate scheduling of inspections and component replacements based on real equipment health data. Sensors not only increase responsiveness to faults but also enable proactive management, which is an important aspect of improving the efficiency of telecom systems (Babak *et al.*, 2021). An important area of research in the field of radio relay station automation is adaptive algorithms, which are capable of automatically adjusting the parameters of equipment operation based on current data on its state. This approach significantly increases the efficiency of system control and optimises operational performance. For instance, studies show that the implementation of adaptive algorithms can lead to reduced response times to emerging failures, minimising downtime and increasing productivity.

Adaptive algorithms account for many factors such as loads, component states and external conditions. This allows systems to dynamically change their parameters, ensuring stable operation even in the face of change. In addition, the use of such algorithms contributes to better resource allocation and reduced maintenance costs. As a result, adaptive algorithms are becoming a key element for improving the reliability and resilience of radio relay

stations by enabling proactive responses to potential faults. This approach not only improves operational management but also provides a basis for further implementation of new technologies and techniques, improving operation of telecommunication systems.

The analysis of the experience of implementing automation in various industries determined that automation helps increase productivity, improve control and reduce maintenance costs. Studies in related fields, such as manufacturing and energy, confirm that automated systems can significantly reduce dependence on the human factor and optimise resource allocation. The opinions and conclusions of other researchers on the direction of automation development in telecommunications were also analysed. In particular, the integration of predictive analytics and machine learning, which are becoming increasingly important for automated management, was prioritised. Predictive algorithms allow not only to effectively predict maintenance needs but also to significantly improve resource planning, which is especially important in a complex telecommunications infrastructure.

Research shows that incorporating machine learning into a control system helps to analyse vast amounts of data, identifying patterns and anomalies that can indicate potential faults. This not only improves response times to faults but also facilitates a proactive approach to management. Systems using predictive analytics become more adaptive and resilient to change, which improves the reliability and efficiency of telecom networks. Thus, the application of such technologies in automation becomes not only desirable but also necessary to ensure sustainable development of telecoms infrastructure. Thus, the qualitative analysis revealed that automation of radio relay stations offers new opportunities to improve the efficiency, reliability and security of telecommunication systems. This stage made it possible to define the key research directions, identify existing knowledge gaps and clarify the tasks for subsequent stages aimed at developing and testing automated solutions.

One of the main results of the study was a reduction in fault response times. Table 2 shows the key results of the quantitative analysis of fault response times before and after the implementation of automation. Following the data, automation has significantly reduced the time required to identify and resolve faults, which is one of the main indicators of system efficiency.

Table 2. Key results of the quantitative time analysis

Parameter	Before automation (min)	After automation (min)	Decrease (min)
Average reaction time	45	15	30

Source: compiled by the authors based on I. Rojek *et al*. (2023), Y. Xin *et al*. (2023)

The reduction in average response time from 45 to 15 minutes demonstrates the high efficiency of automated monitoring and diagnostic systems. The 30-minute reduction significantly reduces equipment downtime and improves overall efficiency in eliminating failures and malfunctions. This data confirms that the introduction of automation in the management of radio relay stations improves the response to critical events, optimising the maintenance process and increasing the reliability and performance of the telecommunications system. A 66.67% reduction in response time indicates a significant improvement in control processes. This was made possible using modern algorithms for automatic monitoring and data processing. The introduction of a real-time fault warning system significantly reduced the time for diagnostics and problem-solving. The analysis of maintenance costs also confirmed the positive impact of automation. Table 3 summarises the annual costs before and after automation.

Table 3. Annual costs before and after automation

Parameter	Before automation (USD)	After automation (USD)	Decrease (USD)
Annual costs	6000	4000	3000

Source: compiled by the authors based on M. Wilson *et al.* (2020)

A 40% reduction in costs confirms the effectiveness of automation. The main factor contributing to this reduction is the reduced need for manual maintenance and improved system reliability. Automation has reduced the number of technical visits and improved overall equipment performance. In addition, automated control systems have provided more accurate monitoring of radio relay station conditions, which has made it possible to identify potential problems in advance and prevent their development. This reduced the number of unscheduled repairs and reduced equipment downtime. As a result, companies that implemented automation not only reduced operating costs but also improved the quality of their services. Better monitoring also contributed to improved system reliability, which had a positive impact on customer satisfaction. They began to receive more consistent and higher quality services, which increased trust in the providers. Improved service levels have become an important competitive advantage in the market, which is especially relevant in the increasingly competitive telecoms industry.

Automation has not only optimised internal processes but also created a more positive brand perception

among customers. Simplifying customer interactions through automated service systems, such as chatbots and online platforms, increases satisfaction and trust. This, in turn, opens up new opportunities for business growth and expansion, allowing the company to attract more customers and improve its reputation in the market. Moreover, positive brand perception helps to build a loyal audience, which is an important aspect of sustainable success. The reliability of radio relay stations was another important aspect of the study. Table 4 shows the percentage of uptime before and after the introduction of automated systems.

Table 4. Percentage of uptime before and after the implementation of automated systems

Parameter	Before automation (%)	After automation (%)	Increase (%)
Reliability	85	98	13

Source: compiled by the authors based on A.P. Kane *et al*. (2022)

A 13% increase in reliability shows that automation of system management contributes to improved functionality. The use of monitoring and predictive analytics technologies identifies potential problems at an early stage and eliminates them before serious failures occur. This not only reduces the likelihood of failures but also minimises equipment downtime, which in turn helps to maintain the smooth operation of telecommunications systems.

An additional advantage is the ability to analyse large amounts of data, which enables more accurate forecasting of system conditions and rapid response to changes. For instance, the data collected during monitoring is used to optimise the performance of components, which leads to increased durability and reduced maintenance costs. Data security in telecommunications systems was also the subject of research. Table 5 shows the number of successful and unsuccessful cyberattack attempts. The 66.67% decrease in successful cyberattack attempts underscores the importance of automation in making systems more secure. The introduction of encryption and multi-level authentication technologies has been a crucial step in the fight against cyber threats. These measures not only strengthen data protection but also form a more robust security architecture that adapts to new challenges. Automating security monitoring processes plays a key role in securing telecom systems. It enables rapid detection and real-time response to suspicious activity, which is critical in the face of ongoing cybersecurity threats. The use of analytical tools, such as intrusion detection systems (IDS), provides the ability to not only record incidents but also predict potential attacks.

Table 5. Number of successful and unsuccessful cyberattack attempts

Parameter	Before automation	After automation	Reduction in attempts
Successful attempts	15	5	10
Unsuccessful attempts	20	3	17

Source: compiled by the authors based on J. Pochmara & A. Świetlicka (2024)

These systems analyse traffic and identify anomalies to prevent attacks before they can cause damage. The use of machine learning in data analysis enhances the effectiveness of such systems, allowing them to adapt to new threats. The integration of automated solutions into security processes helps to significantly reduce risks and minimise potential financial losses, providing a high degree of protection for companies and their customers. Automation is thus becoming an important element in strategies to ensure the security and stability of telecom systems. In addition, automation of access and user rights management minimises the human factor that often causes vulnerabilities. Regular software and security updates are also more easily implemented in automated environments, reducing the likelihood of exploitation of known vulnerabilities. Integrating the Internet of Things into telecom systems is an important aspect of automation. IoT systems allow for better monitoring and control of stations. Table 6 summarises the results of analysing the effectiveness of IoT technologies:

Table 6. Results of analysing the effectiveness of IoT technologies

Parameter	Before IoT implementation	After IoT implementation	Increase in efficiency (%)
Management efficiency	70	90	20

Source: compiled by the authors based on S. Sadiki *et al*. (2018) and I. Appiah *et al*. (2023)

The 20% increase in management efficiency after the introduction of IoT technologies underlines the importance of using modern solutions to improve productivity in telecommunications systems. Automated systems based on IoT provide continuous real-time data collection and analysis, which significantly improves management and monitoring processes.One of the key benefits of the IoT is the ability to integrate various devices and sensors that

provide a stream of up-to-date information about the state of equipment and the environment. This integration allows operators to not only react quickly to changes but also to predict potential problems. For example, sensors can detect deviations from normal equipment operation, enabling serious malfunctions to be prevented in advance (Nussibaliyeva *et al.*, 2024). This approach minimises downtime and reduces maintenance costs, allowing companies to plan resources more efficiently. In addition, the data collected can be used to analyse performance, identify trends and optimise processes, helping to improve the overall efficiency of telecommunications systems. The integration of IoT into radio relay station management creates additional opportunities to improve reliability and safety, which is becoming an important competitive advantage in the market.

IoT systems make it much easier to automate processes in various areas, such as monitoring resource consumption, inventory management and optimising workflows (Hula & Hryha, 2024). For instance, the use of sensors to monitor the condition of equipment not only enables rapid response to changes but also allows maintenance to be planned. This allows faults to be addressed before they occur, minimising downtime and reducing operating costs. With this approach, organisations can manage their resources more effectively and improve performance, creating a more agile and resilient business environment. Thus, the adoption of IoT technologies not only improves productivity and management efficiency but also contributes to a more flexible and adaptive infrastructure that can respond quickly to changes in business needs and the external environment. This, in turn, improves a company's overall competitiveness and allows it to stay ahead in an ever-changing marketplace. These results support the initial hypotheses about the positive impact of automation on telecom systems. The data collected during the study clearly shows that automation leads to significant improvements in various aspects of system performance, including reduced response times, reduced maintenance costs, improved reliability and data security.

Future research may focus on integrating artificial intelligence (AI) and machine learning (ML) technologies to further improve the efficiency and resilience of telecom systems. These technologies are capable of processing large amounts of data, extracting valuable insights from it and predicting potential problems before they occur. For instance, AI can be used to optimise network processes and ML can be used to adapt systems to changing conditions and loads (Lien *et al.*, 2019). Automating the management and analysis of data will not only improve the reliability of systems but also the customer experience, making companies more competitive in a rapidly changing technological environment. The implementation of such solutions will contribute to more proactive infrastructure management and improve the overall resilience of telecom networks.

The use of artificial intelligence (AI) in network management opens up new horizons for optimising monitoring and management (Nesterov, 2023). AI allows systems not only to respond quickly to changes in operations but also to predict potential problems, eliminating them before they occur. For instance, machine learning algorithms can analyse historical traffic data to help optimise data routing and improve resource allocation. This means that during peak times or in the event of unforeseen circumstances, systems can adapt, routing traffic along more efficient routes and minimising delays. As a result, such solutions can increase overall network performance and improve the user experience. AI can also be integrated into automated control systems, which further speeds up the decision-making process and minimises the human factor.

The use of blockchain technologies in telecommunications systems can significantly improve the security and reliability of data transmission. Blockchain provides a decentralised approach to storing information, making systems more resilient to cyberattacks. Each transaction is recorded in a chain of blocks, which helps to guarantee data integrity and protection against unauthorised access. The introduction of such technologies can improve user confidence and reduce the risk of information leaks, which is especially important in the face of growing cybersecurity threats.

DISCUSSION

The study results confirm the significant impact of automation on the efficiency of radio relay station management in telecommunications systems. Reduced fault response times, lower maintenance costs, increased reliability and data security are key indicators of the success of automated systems. These results not only highlight the benefits of automation but also open new horizons for further research in this area.

The first thing to note is the importance of reducing fault response times from 45 minutes to 15 minutes. This means that automated systems can identify and fix problems much faster, which can significantly reduce downtime and therefore improve the overall performance of telecoms systems. This is particularly relevant in the face of today's demands for network uptime and increased system load. Reducing response times not only improves the quality of service but also contributes to increased user satisfaction, which is an important factor in a competitive environment. Comparing our results with the works of other researchers, it can be observed that the decrease in response time is a general trend. For instance, the study by M. Wilson *et al.* (2020) also emphasises that the implementation of automated solutions can significantly reduce the time to troubleshoot, which supports our findings. However, not all studies focus on such significant improvements. Some authors, such as D. Xu *et al.* (2020), emphasise the need for an integrated approach to automation, which involves not only technology implementation but also staff training, which can affect the speed of response.

The second key finding of the current study is a reduction in maintenance costs from USD 6000 to USD 3000, a reduction of 50%. This reduction supports the hypothesis that automation not only improves efficiency but also

reduces costs. The main factor contributing to this reduction is the reduced need for manual maintenance and increased reliability of the systems. J.L. Álvarez *et al*. (2021) also confirm that the integration of sensor technologies can significantly reduce maintenance costs, which coincides with our findings. However, despite these positive results, it is necessary to consider that automation requires an initial investment in technology and staff training. These costs can be significant and should be considered when planning the implementation of automated systems. Future research could therefore focus on analysing the long-term economic feasibility of automation, considering both initial costs and potential savings.

A 13% increase in system reliability is also a significant result. This confirms that control automation not only improves efficiency but also increases the functionality of systems. The use of monitoring technologies and predictive analytics can identify potential problems early and correct them before major failures occur (Bondarenko *et al*., 2019). A.P. Kane *et al*. (2022) also emphasised that predictive maintenance is a key aspect of reliability improvement, which confirms our results. However, following M. Polakova-Kersten *et al*. (2023), high system reliability requires a comprehensive strategy involving both technological and organisational changes. Therefore, further research may focus on the development of integrated management models that combine technology and processes. The 66.67% decrease in successful cyberattack attempts emphasises the importance of automation to improve system security. The introduction of encryption and multi-level authentication systems has significantly reduced risks. This is also consistent with the works of J. Pochmara & A. Świetlicka (2024) who emphasise the importance of secure data channels. Nevertheless, security remains a complex and multifaceted problem. As emphasised by A.O. Osahenvemwen & B.E. Omatahunde (2018), even state-of-the-art systems can be vulnerable to new types of attacks. Therefore, investigating new threats and developing innovative security solutions should be a priority for future research.

A 20% increase in management efficiency after the implementation of IoT technologies also demonstrates the importance of modern solutions. Automated systems based on IoT enable real-time data collection and analysis, leading to faster management decisions (Savytska *et al*., 2024). This provides new opportunities to optimise processes and improve service quality. A comparison of our results with studies by other authors shows that the adoption of IoT technologies is a recognised practice. N.A. Nanjar *et al*. (2024) emphasise that the integration of IoT into telecommunication networks can significantly improve management and overall efficiency. However, successful integration necessitates the availability of appropriate skills among personnel and an infrastructure capable of supporting the new technologies. Thus, the findings of our study confirm the significant impact of automation on the efficiency of telecom systems. They open new horizons for further research and emphasise the importance of an integrated approach to the implementation of new technologies. It is important to continue exploring new solutions that can improve system performance and sustainability in a rapidly changing technological landscape. In summary, the results of our study not only confirm the positive impact of automation on the control efficiency of radio relay stations but also emphasise the need for further research into these processes. The study determined that automation can not only reduce fault response times and maintenance costs but also significantly improve system reliability and safety. This in turn opens up new prospects for the introduction of innovative technologies such as IoT and AI, which can significantly improve the management of telecoms networks.

It is also necessary to address the impact of automation on the organisational structure and work processes of companies. Automation may require a redefinition of employee roles and responsibilities, which can create challenges for human resource management. For instance, with the introduction of automated systems, there may be a need for new occupations and qualifications, which will require investment in training and staff development. Z.G. Khanzad & A.A. Gooyabadi (2022) confirmed that successful implementation of automation requires an integrated approach that includes not only technology but also a change in corporate culture. Thus, with the rapid technological evolution, companies need to proactively adapt to change and invest in developing their human resources. Successful automation can become a competitive advantage, but it requires a strategic approach and consideration of all factors affecting the efficiency of processes.

The importance of analysis of data generated by automation should also be highlighted. Data collected from IoT devices and other automated systems can provide valuable information on equipment performance, user behaviour and potential bottlenecks in the management process. This provides opportunities for more informed, data-driven decision-making, which in turn can improve operational efficiency and reduce costs. It is also worth noting that integrating data analytics into management processes requires appropriate skills in employees so that they can interpret the data and use it to improve system performance. In conclusion, automation is not an end goal, but a process that requires continuous analysis and optimisation.

CONCLUSIONS

The study revealed the effect of automation in improving the control efficiency of radio relay stations in telecommunication technology. The main results show a reduction in fault occurrence time from 45 to 15 minutes, which confirms the hypothesis about the positive effect of managed solutions on the speed of problem limitation. This results in reduced system downtime and provides high performance, which is particularly important in the context of increasing reliability requirements of telecommunication networks. In addition, the study showed that automation reduces maintenance costs by 50%, from USD 6000 to USD 3000, by reducing manual maintenance costs and improving system

reliability. These figures indicate the cost-effectiveness of automated solutions in telecom systems, which could lead to increased profitability for companies in the future. It was also found that system reliability increased by 13%. This result is consistent with the use of technology and predictive analytics for early detection of potential problems. With this automation, the number of successful cyberattacks decreased by 66.67%, indicating an increase in data security due to the implementation of encryption and multi-level authentication systems. The study also found that management efficiency increased by 20% after the introduction of IoT technologies, opening new opportunities to optimise processes and improve service quality. Importantly, successful integration of the Internet of Things requires adequate staff training and appropriate employment.

However, it is worth noting the limitations of the study, in particular, the need for significant initial investment in automation and staff training, which can ensure that a company develops new technologies. The study also does not cover all aspects of automation and therefore requires further research. Based on the findings, it is recommended to research to analyse the cost-effectiveness of automation, as well as to study the impact of new technologies on organisational culture and work processes in telecommunications companies. This will not only improve the results but also ensure sustainable development in the face of market changes.

Future research may focus on adaptive management systems that can respond quickly to changes in the environment and provide a high level of service. This will be a key aspect for achieving growth and increasing the competitiveness of telecommunications companies in the future. A key area for future research may be to study the relationship between automation and changes in organisational culture, as well as to analyse new technologies in the telecoms labour market.

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CONFLICT OF INTEREST

None.

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Тайрь Мойдунов
Доктор технічних наук
Ошський технологічний університет імені М.М. Адишева
723503, вул. Ісанова, 81, м. Ош, Киргизька Республіка
https://orcid.org/0009-0002-4328-3269

Адилькан Сарімсаков
Кандидат технічних наук
Ошський технологічний університет імені М.М. Адишева
723503, вул. Ісанова, 81, м. Ош, Киргизька Республіка
https://orcid.org/0009-0004-3175-5796

Салтанат Оморова
Аспірант
Ошський технологічний університет імені М.М. Адишева
723503, вул. Ісанова, 81, м. Ош, Киргизька Республіка
https://orcid.org/0009-0005-5627-7935

Алтинай Ничсанова
Аспірант
Ошський технологічний університет імені М.М. Адишева
723503, вул. Ісанова, 81, м. Ош, Киргизька Республіка
https://orcid.org/0009-0007-7100-1982

Жоомарт Матісаков
Аспірант
Ошський технологічний університет імені М.М. Адишева
723503, вул. Ісанова, 81, м. Ош, Киргизька Республіка
https://orcid.org/0009-0009-5622-3901

Аналіз системи управління радіорелейними станціями з використанням IT-технологій

Анотація. Дослідження зосереджене на теоретичному аналізі систем керування радіорелейними станціями, що використовують сучасні інформаційні технології. Основною метою роботи стало виявлення потенціалу підвищення продуктивності, надійності та економічної ефективності таких систем. У рамках аналізу розглядалися передові сенсорні технології, алгоритми автоматизації та методи моніторингу, які могли істотно знизити витрати на обслуговування і прискорити реагування на несправності. Розглянуто ключові аспекти, що впливають на продуктивність радіорелейних станцій, включно з впливом кліматичних умов і різними сценаріями експлуатації. Підкреслено значущість інтеграції автоматизації для підвищення надійності роботи систем і зниження впливу людського фактору. Акцентовано увагу на відповідності запропонованих рішень міжнародним стандартам радіорелейного зв'язку, що спростило інтеграцію з наявними мережами та можливість майбутньої модернізації. Результати дослідження обґрунтували необхідність автоматизації радіорелейних систем і створили теоретичну базу для їхнього подальшого розвитку та вдосконалення, що відкрило нові можливості для поліпшення експлуатаційних характеристик і підвищення стійкості до потенційних збоїв. Проаналізовано впровадження нових підходів до управління даними та аналізу, що давало змогу оперативно реагувати на зміни в умовах експлуатації та оптимізувати ресурси. Ці аспекти забезпечили конкурентні переваги в умовах швидко мінливого середовища телекомунікаційних технологій, підкреслюючи важливість гнучкості та адаптивності систем для ефективної роботи. У підсумку, вивчення теоретичних основ автоматизації могло стати основою для практичних рекомендацій щодо впровадження інноваційних технологій в управління радіорелейними станціями

Ключові слова: автоматизація зв'язку; сенсорні модулі; машинне навчання; віддалений моніторинг; підвищення надійності; економічна ефективність