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Evaluation of the possibility of using an antenna switch with a wideband matching device

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ABSTRACT

This paper investigates the feasibility of integrating a broadband matching device (BMD) with a high-frequency switch into the antenna system of the MIC RL-400M radio relay station, part of the "ROSA" radar complex. The aim is to compensate for antenna impedance changes caused by adverse weather conditions such as snowfall, icing, and wet snow, which reduce power transmission efficiency. Various types of high-frequency switches, including relays, PIN diodes, and transistors, were analyzed. A transistor-based switch (HMC349AMS8G) was selected due to its low insertion loss, high reliability, and wide operating frequency range. The BMD structure was synthesized to minimize impedance variation, and its performance was evaluated through simulation in AWR Microwave Office and experimental measurements in the 394–450 MHz range. Results showed an average power loss reduction of 0.7 dB and a 6.9% increase in radio link range compared to operation without a switch. The proposed solution enhances the stability and efficiency of radar and radio relay systems, ensuring reliable operation in challenging environmental conditions.

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1. INTRODUCTION

Modern radar [1]–[3] and radio relay communication systems [4]–[6] play a key role in ensuring stable command and control of troops and transmission of data on the radar situation. Such systems are especially important in combat conditions [7], [8], where rapid deployment, reliability and resistance to external influences are required [9], [10]. The MIC RL-400M radio relay station of the ROSA radar complex is a striking example of equipment that provides automatic information exchange in the frequency range from 394 to 450 MHz. However, the operation of such systems in difficult weather conditions, including heavy snowfall, icing, and temperature changes, leads to a change in the antenna impedance, which reduces the efficiency of power transmission between the receiving and transmitting modules (TPM) and the antenna system. These changes can negatively affect the range of the radio link and the quality of the received signal, which is critical in operational control and combat conditions.

The relevance of the topic lies in the need to improve the reliability and efficiency of radar systems in extreme operating conditions. Stable operation of antennas and optimization of power transmission are especially important to ensure high accuracy of data transmission [11], [12], which ultimately affects the success of military operations and control in critical situations. The problem of the study is a significant decrease in the power transfer coefficient (PTC) of radio relay system antennas under adverse weather conditions [13]. This is caused by a change in the antenna impedance, which leads to power losses and a decrease in the range of the radio link. Without eliminating this problem, the overall efficiency of the communication system decreases, which can affect its ability to transmit important data in extreme operating conditions. The solution to the problem involves the development and implementation of a wideband matching device (WMD) in the signal transmission path [14]–[16], capable of compensating for impedance changes. In addition, it is proposed to use high-frequency switches that will allow choosing the optimal antenna operating mode depending on the operating conditions. This will stabilize power transmission and increase the reliability of radio relay stations. The purpose of this work is to study the possibility of using a high-frequency switch together with a control unit to compensate for changes in antenna impedance caused by adverse weather conditions. To achieve this goal, it is necessary to analyze existing types of switches, synthesize an optimal control unit and simulate the proposed solution to evaluate its effectiveness. As part of the study, an analysis of various types of switches was carried out, a control unit was synthesized taking into account changing antenna characteristics and external factors, and a simulation of the proposed solutions was performed. The results of the work are of great practical importance for improving the characteristics of radio relay stations and increasing their operational capabilities in a wide range of weather conditions.

2. METHOD

In radio communication systems, which are of exceptional importance in organizing stable command and control of troops in modern combat conditions, as well as transmitting data on the radar situation, very high frequency/ultra high frequency (VHF/UHF) radio stations are used [17], [18], allowing operation in a wide frequency range (30-3000 MHz) in various operating conditions [19], [20]. Thus, the ROSA-RB radar complex, which is used both in stationary and mobile modes, ensures detection of aerial reconnaissance or attack assets flying at low and ultra-low altitudes and posing the greatest threat, where the VHF radio relay station MIC RL-400M is used as information transmission equipment (Figure 1). The radio relay station [21], [22] ensures automatic exchange of radar information, commands, reports and transmission of output route information from a small-sized radar station [23]–[25] to remote control systems (RCS).

Figure 1. Radio relay station MIK-RL400M

The experimental measurements were carried out using a Rohde & Schwarz ZNB20 vector network analyzer (VNA) connected to the antenna system via low-loss coaxial cables with N-type connectors. The analyzer was calibrated using the short-open-load-through (SOLT) method with a certified calibration kit prior to each measurement series to ensure accuracy. Baseline "normal" conditions were defined as ambient temperature of +20 ±2 °C, relative humidity of 40–50%, wind speed below 2 m/s, and absence of precipitation. Environmental parameters during experiments were monitored using a portable weather station (Vaisala WXT530). For each weather condition (normal, snowfall, icing, and wet snow), impedance measurements were repeated five times at one-hour intervals to minimize transient effects, and the results were averaged. Standard deviation and 95% confidence intervals were calculated to quantify measurement uncertainty. The simulation was performed in AWR Microwave Office using an equivalent circuit model of the antenna system with and without the broadband matching device (BMD) and high-frequency switch. The frequency sweep was set from 394 to 450 MHz with a step size of 1 MHz. The load impedance was set to 50 Ω, and the BMD parameters were based on the synthesized reactive elements shown in Table 1. Boundary conditions assumed free-space propagation without multipath effects. The choice of this configuration reflects typical operational conditions of the MIC RL-400M in the field, enabling realistic performance estimation.

Table 1. Parameters of reactive elements of a BMD

Element	Value (nominals)	Quality
C_1	24.4 pF	200
C_2	7.15 pF	200
L_1	178 nH	80
L_2	28.7 nH	80

During combat operations, the radar complex is forced to constantly maneuver and change its position. In such a situation, the complex is often forced to conduct combat operations on unprepared terrain and in difficult weather conditions. This leads to changes in the range and direction of the radio link for transmitting data by the radio relay station. It should be noted that changes in the operating conditions of the RTS lead to variations in the impedance of the antenna device (AD) and, consequently, the level of power transmission between the receiving and TPM and the antenna. This reduces the potential capabilities of the station and can affect decisions made during troop control and air combat. To solve the problem of increasing the efficiency of power transmission of the radio relay station MIK RL-400M of the ROSA radar complex, a comprehensive approach was used, including the following stages.

2.1. Experimental studies

Antenna impedance measurements were carried out in the frequency range from 394 to 450 MHz under various weather conditions: snowfall, icing, wet snow, and normal conditions. The obtained data are presented as a dependence of the real and imaginary parts of the antenna impedance (1):

$$Z(f) = R(f) + j \tag{1}$$

where $R(f)$ is the active component of impedance, and $X(f)$ is the reactive component. The experiment established that weather conditions cause changes in $R(f)$ and $X(f)$, leading to a reduction in the PTC $K(f)$. This deviation is illustrated in the graphs of the dependence of $K(f)$ on frequency.

2.2. Synthesis of a broadband matching device

The BMD synthesis was performed to minimize changes in antenna impedance and ensure a high PTC. In (2) served as the basis for the synthesis:

$$K(f) = \frac{P_{load}(f)}{P_{source}(f)} = | \frac{Z_{load}}{Z_{source}} \tag{2}$$

where P_load is the power transmitted to the load, P_source is the source power, Z_load and Z_source are the impedances of the load and source, respectively. Table 1 presents the parameters of reactive elements used in the BMD. The table lists the following elements: two capacitors (C_1 and C_2) and two inductors ($L1$ and $L2$). For each element, the nominal values are provided, expressed in picofarads (pF) for capacitors and nanohenries (nH) for inductors. The table also includes the quality factors, characterizing the performance of the reactive elements.

Three types of high-frequency switches were analyzed: relays, PIN diodes, and transistors. Based on the comparative characteristics, a circuit based on the HMC349AMS8G transistor switch was selected, which has the following parameters: bandwidth of 100 MHz–4 GHz, insertion loss of 0.7 dB at a frequency of f≤2 GHz, isolation of 43 dB.

2.3. System simulation

Simulation was performed in AWR Microwave Office. Two configurations were considered, such as antenna operation with a bias control system (BCS) without a switch and antenna operation with a BCS and a switch. The graph of the dependence of the PTC $K(f)$ on frequency is shown in Figure 2.

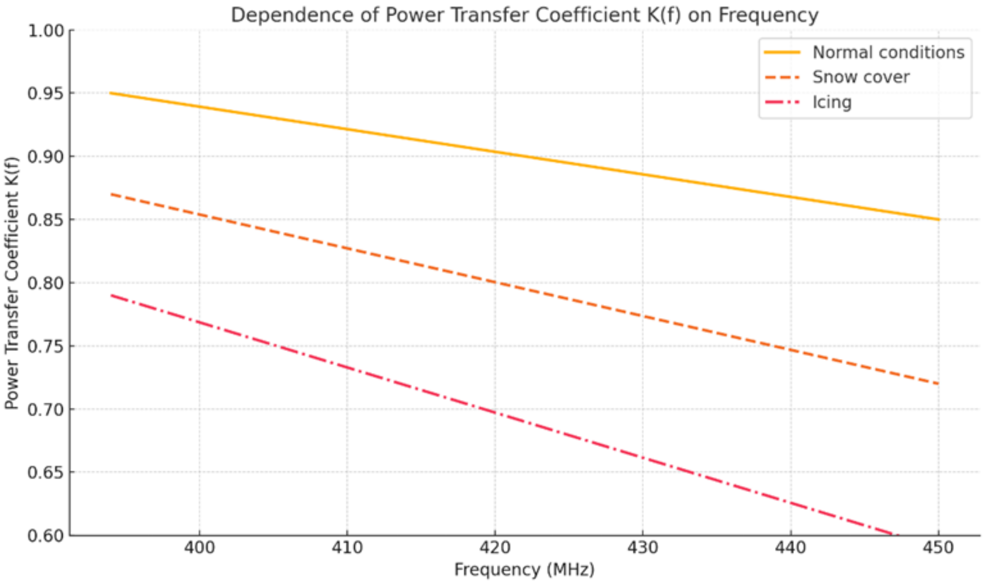

Figure 2. Dependence of PTC $K(f)$ on frequency under different conditions

2.4. The final formula for assessing the range of the radio link

The results of the modeling showed that the synthesized matching/impedance-matching unit together with the switch allows to reduce power losses and increase the range of the radio link (3):

$$R_{max} = \sqrt{\frac{P_{tx}G_tG_r\lambda^2}{(4\pi)^2P_{min}}} \tag{3}$$

where P_{tx} is the transmitter power, G_t, G_r is the gain of the transmitting and receiving antennas, λ is the wavelength, and P_min is the minimum receiver power. The comparison showed that using the SHSU with a switch increases the range of the radio link by 6.9%. All presented methods and models confirmed the effectiveness of the proposed solution, providing a significant increase in the stability of signal transmission and the reliability of the radio relay station in difficult operating conditions.

To select the most suitable high-frequency switch for integration with the BMD, a comparative evaluation of three widely used types relays, PIN diodes, and transistor switches was carried out. The comparison considered critical parameters such as operating frequency range, insertion loss, isolation, switching speed, and overall reliability. The summarized results are presented in Table 2.

Table 2. Comparative characteristics of high-frequency switches

Switch type	Frequency range	Insertion loss	Isolation	Switching speed	Reliability	Comment
Relay	kHz–GHz	High	Medium	Slow (ms)	Medium	Not suitable for broadband, limited lifetime
PIN diode	MHz–GHz	Medium	Medium	Fast (ns–μs)	High	Requires biasing, higher complexity
Transistor (HMC349**A**MS8G)	100 MHz–4 GHz	0.7 dB @ f≤2GHz	43 dB	Fast (ns)	High	Optimal for wideband and low-loss integration

As seen from Table 2, relays are limited by high insertion loss and slow switching speed, which makes them unsuitable for broadband and high-reliability radar applications. PIN diodes demonstrate faster operation and better reliability but require additional biasing circuitry and still introduce moderate losses. In contrast, the transistor-based switch HMC349AMS8G provides the most balanced performance, with low insertion loss, wide operating bandwidth, and high isolation. Therefore, this device was selected as the optimal solution for integration with the broadband matching network in the MIC RL-400M radio relay system.

3. RESULTS AND DISCUSSION

To confirm the above, an experiment was conducted using the antenna systems of the MIK-RL400M radio relay station. The experimental studies were conducted in several stages. The idea of the studies was to measure the impedance of the AU in natural conditions of its operation (in heavy snowfall and icing, when wet snow hits the AU, as well as in normal conditions, without precipitation) in the frequency band from 394 to 450 MHz. The dependencies of the impedance of the AU in normal conditions were used as a reference value. One of the stages of the experiment is shown in Figure 3.

The results of the experimental studies are presented as the dependence of the real component of the complex impedance of the matching device (Figure 3(a)) on frequency under various operating conditions. Similarly, the imaginary component of the complex impedance is shown in Figure 3(b). These dependencies illustrate the impact of different environmental factors on the performance of the matching device.

(a) (b)

Figure 3. Measurement of matching device parameters under snow cover conditions; (a) measurement setup with snow accumulation on the antenna system and (b) laptop interface displaying measurement data during snow cover conditions

The proposed solution can be applied not only to the MIC RL-400M but also to other radar and communication systems operating in similar frequency ranges, including shipborne and mobile platforms. Integration of adaptive matching and switching devices can enhance operational readiness in military and civilian applications, such as air traffic control, coastal surveillance, and emergency communications. The approach is scalable to higher frequency bands with appropriate re-design of the matching network and selection of suitable switch components.

Quantitative comparison between the baseline (antenna without BMD and switch) and the proposed configuration (antenna with BMD and HMC349AMS8G switch) is presented in Table 2. On average, the improved configuration reduced power losses by 0.7 dB and extended the radio link range by 6.9%. These values were consistent across repeated trials, confirming the robustness of the approach.

The conducted study confirmed the effectiveness of integrating a high-frequency switch with a BMD in the antenna system of the MIC RL-400M radio relay station, particularly under adverse weather conditions. Experimental results showed that environmental factors such as snowfall and icing significantly affect the real and imaginary components of antenna impedance, which leads to a reduction in the PTC. The synthesized BMD, based on reactive elements selected for optimal frequency compensation, successfully minimized impedance mismatches. The integration of the transistor-based switch HMC349AMS8G demonstrated considerable advantages in terms of adaptability, power efficiency, and operational bandwidth.

This solution proved to be superior to alternatives such as relays and PIN diodes, which are limited by higher losses or additional circuit complexity. System-level simulations further confirmed that the proposed configuration increases the radio link range by 6.9%, ensuring more reliable communication during mobile operations. Although a 6.9% increase in range may appear modest, in operational scenarios this translates into several additional kilometers of reliable communication. For radar and relay systems used in mobile or combat operations, this extended range can determine whether a stable link is maintained under adverse weather conditions, directly influencing situational awareness and command effectiveness. The practical value of the developed approach is especially relevant for modern radar platforms, where robust performance and mobility are critical under operational stress. The choice of a transistor switch also reflects the growing demand for compact, low-loss, and broadband-compatible components in advanced communication systems. Overall, the results contribute to improving the stability and efficiency of radio relay systems and can serve as a foundation for further modernization of radar and relay technologies.

The results of this study complement and extend prior research on antenna matching under adverse weather conditions by demonstrating the added value of integrating a BMD with a transistor-based switch. Unlike earlier works that primarily analyzed switches or matching networks separately, the present study highlights the benefits of their combined use, thereby offering a novel and more resilient solution for radar and relay applications.

In future studies, the focus will be on deeper integration of the BMD and transistor switch into adaptive antenna systems. This includes optimizing the matching network for multi-band operation, testing switch performance under extreme environmental stress (icing, high humidity, and rapid temperature fluctuations), and developing real-time control algorithms that dynamically select optimal matching and switching configurations. Such improvements will ensure more robust antenna matching and reliable switch integration across a broader class of radar and relay systems. Future work will specifically focus on strengthening the integration between the BMD and the high-frequency switch. In particular, future studies will investigate the co-optimization of switch states and matching-network reactances to achieve real-time impedance compensation under dynamically changing environmental conditions. Another important direction is the development of adaptive algorithms capable of monitoring the antenna's impedance in situ and automatically selecting the optimal switch configuration to maximize the power-transfer coefficient. Additionally, expanding the proposed methodology to multiband antennas and higher-frequency relay systems will enable broader applicability of the integrated switching-matching architecture.

While the proposed approach demonstrates measurable improvements, several limitations should be acknowledged. Measurement uncertainty, primarily due to VNA calibration drift and connector repeatability, could influence the reported power loss values by up to ±0.05 dB. Environmental variability during field tests, particularly fluctuations in wind speed and snow accumulation rate, may have introduced additional variations in impedance readings. The simulation model in AWR Microwave Office assumes free-space propagation and does not account for terrain effects or multipath interference, which could affect performance in real deployments. Furthermore, the study was limited to a single frequency range (394–450 MHz), and results may not directly transfer to other frequency bands without re-optimization of the BMD parameters.

4. CONCLUSION

The study confirmed the effectiveness of integrating a BMD with a high-frequency transistor switch into the antenna system of the MIC RL-400M radio relay station to mitigate impedance variations under adverse weather conditions. Experimental measurements in the 394–450 MHz range showed that snowfall, icing, and wet snow significantly degraded the PTC, while the proposed solution reduced average power loss by 0.7 dB and extended the radio link range by 6.9% compared to the baseline configuration. The transistor-based switch (HMC349AMS8G) was selected as the optimal choice due to its low insertion loss, wide operating frequency range, and high isolation, ensuring reliable operation in severe environmental conditions. The results have practical value for enhancing the stability and efficiency of both stationary and mobile radar and radio relay systems. Future work will focus on optimizing the BMD for broader frequency coverage, testing under more extreme environmental conditions, and developing automated control algorithms to dynamically adjust antenna matching in real time.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, Assel Yerzhan, upon reasonable request. Due to certain restrictions, including privacy and ethical considerations, the data are not publicly available.

REFERENCES

[1] V. Shatov *et al.*, "Joint Radar and Communications: Architectures, Use Cases, Aspects of Radio Access, Signal Processing, and Hardware," *IEEE Access*, vol. 12, pp. 47888–47914, 2024, doi: 10.1109/ACCESS.2024.3383771.

[2] F. Liu *et al.*, "Seventy Years of Radar and Communications: The road from separation to integration," *IEEE Signal Processing Magazine*, vol. 40, no. 5, pp. 106–121, Jul. 2023, doi: 10.1109/MSP.2023.3272881.

[3] S. S. Kari and A. A. B. Raj, "Evolutionary Developments of Today's Remote Sensing Radar Technology—Right From the Telemobiloscope: A review," *IEEE Geoscience and Remote Sensing Magazine*, vol. 12, no. 1, pp. 67–107, Mar. 2024, doi: 10.1109/MGRS.2023.3329928.

[4] D. Semenov, A. Bugrov, O. Bolkhovskaya, and A. Maltsev, "Experimental Study of Millimeter-Wave (E-band) Radio Relay Link Characteristics," in *2025 Wave Electronics and its Application in Information and Telecommunication Systems (WECONF)*, May 2025, pp. 1–4, doi: 10.1109/WECONF65186.2025.11017143.

[5] T. Kravaica, "Improving the integrity of military-defence communication systems using network access points with a focus on terrestrial radio-relay links," *Strategos: Znanstveni Časopis Hrvatskog Vojnog Učilišta ``Dr. Franjo Tuđman''*, vol. 6, no. 2, pp. 177–206, 2022.

[6] A. P. Zhuravlev, "Modulation Parameters Analysis of Modern Communication Systems," in *2022 Systems of Signals Generating and Processing in the Field of on Board Communications*, Mar. 2022, pp. 1–5, doi: 10.1109/IEEECONF53456.2022.9744089.

[7] N. Velastegui, E. Pavon, H. Jacome, F. Torres, and M. Pico, "Technological advances in military communications systems and equipment," *Minerva*, vol. 3, no. 8, pp. 61–73, Aug. 2022, doi: 10.47460/minerva.v3i8.65.

[8] L. Uryvsky, A. Gnashchuk, S. Osypchuk, and A. Moshynska, "Comprehensive Approach for Radio Equipment Design to Ensure Reliable UAVs Operations," in *Lecture Notes in Electrical Engineering*, vol. 965, 2023, pp. 140–174, doi: 10.1007/978-3-031-24963-1_9.

[9] S. Kumar and N. Sharma, "Emerging Military Applications of Free Space Optical Communication Technology: A Detailed Review," *Journal of Physics: Conference Series*, vol. 2161, no. 1, p. 012011, Jan. 2022, doi: 10.1088/1742-6596/2161/1/012011.

[10] M. Dansarie, "Security Issues in Special-Purpose Digital Radio Communication Systems: A Systematic Review," *IEEE Access*, vol. 12, pp. 91101–91126, 2024, doi: 10.1109/ACCESS.2024.3420091.

[11] Z. D. Manbetova, Z. S. Abdimuratov, K. S. Chezhimbayeva, Z. M. Zhazykbayeva, and M. N. Imankul, "Comparative analysis of methods and model of protection against electromagnetic fields in cellular communication," *International Journal on Communications Antenna and Propagation*, vol. 11, no. 1, pp. 1–8, Feb. 2021, doi: 10.15866/irecap.v11i1.20062.

[12] X. Qu *et al.*, "An Indoor Moving Target Relocation Method Based on Interferometric Phase of Dual-Channel UAV-Mounted Through-the-Wall Radar," in *IEEE Transactions on Instrumentation and Measurement*, vol. 74, pp. 1-13, 2025, Art no. 8506513, doi: 10.1109/TIM.2025.3553937.

[13] G. Ansabekova *et al.*, "Development of intelligent protection and automation control systems using fuzzy logic elements," *International Journal of Electrical and Computer Engineering*, vol. 14, no. 1, pp. 556–565, Feb. 2024, doi:

10.11591/ijece.v14i1.pp556-565.
[14] B. Nakisbekova, A. Yerzhan, P. Boykachev, Z. Manbetova, M. Imankul, and P. Dunayev, "Study of the Characteristics of Broadband Matching Antennas for Fifth-Generation Mobile Communications Based on New Composite Materials," *International Journal of Electrical and Computer Engineering*, vol. 14, no. 3, pp. 2885–2895, 2024, doi: 10.11591/ijece.v14i3.pp2885-2895.
[15] M. Yuan *et al.*, "MOFs derived multi-scale lamellar network for broadband electromagnetic wave absorber," *Carbon*, vol. 216, p. 118504, 2024, doi: 10.1016/j.carbon.2023.118504.
[16] F. Serbet and T. Kaya, "Statistical analysis and EEG signal filtering using design of window function based on optimization methods," *Journal of Circuits, Systems and Computers*, vol. 32, no. 18, 2023, doi: 10.1142/S0218126623503061.
[17] N. Faruk *et al.*, "Large-scale radio propagation path loss measurements and predictions in the VHF and UHF bands," *Heliyon*, vol. 7, no. 6, 2021, doi: 10.1016/j.heliyon.2021.e07298.
[18] U. Ukommi and E. Ubom, "Impact Assessment of Elevation Angles on Signal Propagation at VHF and UHF Frequencies for Improved Rural Telephony," *ABUAD Journal of Engineering Research and Development (AJERD)*, vol. 6, no. 2, pp. 136–142, 2023, doi: 10.53982/ajerd.2023.0602.13-j.
[19] A. Z. Rasidi, D. M. Ali, N. Ya'acob, A. L. Yusof, and D. S. Ametefe, "Performance Measurement of Tactical Radio Station Deployment Using Very High Frequency (Vhf) in Suburban Area Environment," *Defence S and T Technical Bulletin*, vol. 16, no. 1, pp. 1–12, 2023.
[20] D. Wright, "Investigation into joint use of UHF and VHF bands for future Internet of Things: field test platform and measurement campaigns," Ph.D thesis, University of Sheffield, 2021.
[21] Q. Li, L. Hu, J. Zhang, J. Chen, and G. Wu, "Multiple-access relay stations for long-haul fiber-optic radio frequency transfer," *Optics Express*, vol. 30, no. 11, p. 18402, May 2022, doi: 10.1364/OE.460704.
[22] L. Li, J. Xu, N. Yang, and Y. Li, "Sleep Strategy Based on Double DQN Method for Satellite Ground Relay Station," *IEEE Access*, vol. 12, pp. 130663–130674, 2024, doi: 10.1109/ACCESS.2024.3447633.
[23] H. M. T. Mustafa, J.-I. Baik, H.-K. Song, M. Adnan, and W. M. Awan, "Spectral Efficiency Maximization for Mixed-Structure Cognitive Radio Hybrid Wideband Millimeter-Wave Transceivers in Relay-Assisted Multi-User Multiple-Input Multiple-Output Systems," *Sensors*, vol. 24, no. 12, p. 3713, Jun. 2024, doi: 10.3390/s24123713.
[24] J. Xiang, L. Yang, K. Guo, N. Zlatanov, and Y. Wu, "Performance Evaluation of UAV-Aided Radio Frequency-UAC Relaying Systems," *IEEE Internet of Things Journal*, vol. 11, no. 13, pp. 24183–24195, Jul. 2024, doi: 10.1109/JIOT.2024.3388581.
[25] Y. Lin, Y. Ai, Z. Xu, J. Wang, and J. Li, "Adaptive Resource Allocation for Emergency Communications with Unmanned Aerial Vehicle-Assisted Free Space Optical/Radio Frequency Relay System," *Photonics*, vol. 11, no. 8, p. 754, Aug. 2024, doi: 10.3390/photonics11080754.

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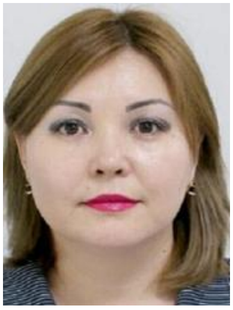

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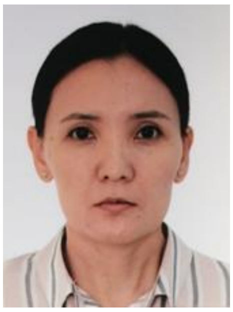

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