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Optimized design of energy efficiency of agricultural small base station in Aksu region based on RF power amplifier

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ABSTRACT
The purpose of this study is to solve the energy efficiency problem of small agricultural base stations, propose an optimal design scheme based on RF power amplification, and verify its effectiveness through simulation experiments. In order to achieve the research purpose, this paper first defines the objectives and principles of energy efficiency optimization design, and puts forward the energy efficiency optimization technology based on RF power amplification. On this basis, a complete set of energy efficiency optimization design scheme for small agricultural base stations is designed. And by building a simulation platform, set the parameters close to reality, and simulate the operation state of the base station in different scenarios. The simulation results show that the stability of the algorithm in this paper is considerable under different loads. Even if the load is large, the stability of this method can reach above 89%. The proposed energy efficiency optimization scheme can significantly reduce the energy consumption of the base station and improve the overall energy efficiency performance under different load and interference conditions. This result proves the effectiveness and superiority of the scheme and provides strong support for practical application.

Keywords: Radio frequency power amplification, Aksu region, Agricultural small base station, Energy efficiency optimization design

1. Introduction

With the rapid development of the mobile Internet, multimedia services such as audio, video and games have gradually replaced traditional voice, SMS, etc. as the main types of services in the communication network, and the amount of services in the network has also skyrocketed [1-3]. In the future 5G era, different kinds of services with higher requirements on service rate will appear, such as virtual reality, augmented reality, etc. In addition, along with the rise of smart wearable devices and the Internet of Things (IoT), the number of terminal devices in the network will show a

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geometric progression [4-6]. This puts forward many new requirements for the next-generation communication network, such as providing 100Mbps-1Gbps experience rate anytime, anywhere, 100 times the connectivity of devices, and millisecond low latency. Base station deployment, the most critical part of communication network construction, is the core of the industry's attention. The new generation of innovative base station technologies represented by high efficiency amplifier, multicarrier frequency technology, distributed architecture, and enhanced indoor coverage will allow operators to realize high-performance and low-cost network deployment [7-9]. Among them, the amplifier efficiency issue is a hotspot pursued by all manufacturers. This is because improving power amplifier efficiency not only saves operators' electricity cost and investment in supporting facilities such as power supply, but also reduces the heat dissipation requirement of the whole machine and enhances the stability of the equipment [10-12]. In terms of cost, the power amplifier is the most expensive device on the base station. The power amplifier is one of the core components in a small base station, which is responsible for amplifying and feeding the low-power RF signal from the base station to the antenna and transmitting it to the long-distance mobile terminal [13-14]. As mobile telecom operators have started to provide ultra-high speed services, the power requirements of wireless network infrastructure have reached unprecedented levels. Data-driven services are gradually becoming a more important part of the wireless infrastructure, which makes RF power amplifier performance a necessity. And by skillfully combining the advantages of RF power amplifiers with small agricultural base stations, high levels of energy efficiency and good pre-distortion capability can be achieved, while significant cost savings are realized and the total power consumption of the base station system is also significantly reduced [15-19].

The innovation of this paper is mainly reflected in the following aspects:

1) Systematic energy efficiency optimization scheme: Different from the traditional energy efficiency optimization method which only focuses on a single device or technology, this paper proposes a systematic energy efficiency optimization scheme. The scheme comprehensively considers the base station equipment, network architecture, resource allocation and other aspects to ensure the maximum energy efficiency in the whole system.

2) Energy efficiency optimization technology based on RF power amplification: This paper innovatively proposes energy efficiency optimization technology based on RF power amplification. By adopting advanced RF power amplifier and other related technologies, the energy consumption of power amplifier is reduced and its efficiency is improved, thus the energy efficiency performance of small agricultural base stations is significantly improved.

3) Emphasize the sustainability and long-term development of the scheme: Unlike many schemes that only focus on short-term energy efficiency improvement, this paper particularly emphasizes the sustainability of the proposed scheme and its impact on the long-term sustainable development of the base station. This innovation ensures that the optimization scheme can not only significantly improve the energy efficiency in the short term, but also lay a solid foundation for the long-term development of the base station.

With the continuous development of new generation information technologies such as 5G and Internet of Things, wireless communication networks will develop in the direction of higher energy efficiency, lower delay and wider coverage. At the same time, with the application of artificial intelligence, big data and other technologies, the energy efficiency optimization of wireless communication networks will be more intelligent and automated. Therefore, this study not only has current application value, but also has future development prospects.

Firstly, this study analyzes the energy efficiency status of agricultural small base stations in Aksu area, and makes clear the existing problems and challenges. Then, based on RF power amplification technology, an energy efficiency optimization design scheme for small agricultural base stations is proposed. The scheme will be optimized from hardware design, power control, resource allocation and other aspects to improve the energy efficiency of small agricultural base stations. Then, the feasibility and effectiveness of the proposed scheme are verified by simulation experiments, and the experimental results are analyzed and discussed. Finally, the research results are summarized, and the improvement direction and application suggestions are put forward.

2. Radio frequency power amplification technology

The RF power amplifier operates based on the amplification capabilities of semiconductor components like transistors or field-effect transistors. Its mechanism involves the amplification of the input signal by these transistors after it traverses the input matching network, and is subsequently relayed to the load through the output matching network. During this amplification, the amplifier must receive adequate DC power to uphold its operational state and transform DC energy into AC signal energy. To enhance the amplifier's efficiency and linearity, a range of circuit designs and control methods are employed, including power back-off, negative feedback, feedforward, and predistortion techniques.

The performance indexes of RF power amplifier mainly include gain, efficiency, linearity, bandwidth and stability, as shown in Table 1.

Table 1. Performance index of RF power amplifier

Performance index	Definition	Significance
Increase	Ratio of output power to input power of amplifier	Reflect the amplification ability of the amplifier
Efficiency	The ability of amplifier to convert DC power supply energy into AC signal energy.	Directly affect the energy consumption and heat dissipation of the amplifier.
Linearity	The ability of the output signal to remain linear when the input signal changes.	Reduce signal distortion and improve communication quality.
Bandwidth	The signal frequency range that the amplifier can amplify.	Determine the application range of the amplifier
Stability	Ability to maintain stable performance under various working conditions.	Important embodiment of amplifier reliability

Radio frequency power amplification technology is widely used in wireless communication, radar, satellite communication, radio and television and other fields. In wireless communication system, RF power amplifier is an indispensable key component in base stations, mobile phones, wireless network cards and other equipment. In radar system, RF power amplifier is used to amplify the transmitted signal to a sufficient power level to detect the target. In satellite communication, the RF power amplifier is used to amplify the signal transmitted by the ground station to the intensity that can penetrate the atmosphere and reach the satellite. In radio and television, RF power amplifiers are used to amplify audio and video signals to a sufficient power level to cover a wide receiving area.

3. Methodology

1) General situation of agriculture in Aksu region. Aksu region, located in the southwest of Xinjiang Uygur Autonomous Region, is a region mainly engaged in agricultural production. The region has a suitable climate, fertile land and abundant water resources, which is suitable for planting a variety of crops. In recent years, with the progress of agricultural science and technology and the adjustment of agricultural industrial structure, agricultural production in Aksu has developed rapidly and become one of the important agricultural production bases in Xinjiang and even the whole country.

2) Construction of existing agricultural small base stations. In order to meet the needs of agricultural informatization in Aksu area, a certain number of small agricultural base stations have been built in this area in recent years. These small base stations are mainly used to provide wireless communication network services and support agricultural Internet of Things, intelligent irrigation, agricultural product traceability and other applications. However, due to the limitation of funds, technology and management, there are still some shortcomings in the construction scale, coverage and service quality of the existing agricultural small base stations.

3) Analysis of energy efficiency of small agricultural base stations. Through the investigation and analysis of existing agricultural small base stations, it is found that energy efficiency is one of the important factors restricting its development. It is embodied in the following aspects: First, aging equipment and backward technology lead to high energy consumption; Second, the lack of effective energy efficiency management means and mechanisms; Third, unreasonable resource allocation leads to energy waste; Fourth, there is a lack of energy efficiency optimization design and standards for small agricultural base stations. These problems not only affect the operation efficiency and service quality of small agricultural base stations, but also increase the operation cost and maintenance difficulty.

4) The necessity of improving the energy efficiency of small agricultural base stations. Improving the energy efficiency of agricultural small base stations is of great significance for promoting the development of agricultural informatization in Aksu area. First of all, improving energy efficiency can reduce operating costs and maintenance difficulties, and enhance the sustainable development capacity of small agricultural base stations. Secondly, optimizing energy efficiency will help reduce energy consumption and carbon emissions and promote green and low-carbon development. Finally, improving the energy efficiency of small agricultural base stations can promote the development and innovation of related industries and contribute to agricultural modernization in Aksu region and even the whole country. Therefore, it is of great practical significance and long-term development value to carry out the research on energy efficiency optimization design of agricultural small base stations in Aksu area based on RF power amplification.

4. Optimal design scheme of energy efficiency for agricultural small base stations

In the energy efficiency optimization design of small agricultural base stations, the primary goal is to reduce energy consumption and improve energy efficiency, while ensuring that the communication quality and coverage of the base stations are not affected. Specifically, the design objectives include reducing the overall power consumption of base station equipment, improving the efficiency of power amplifiers, optimizing resource allocation and scheduling algorithms, etc. In the design process, the principles in Table 2 need to be followed.

Table 2. Optimal design principle of base station energy efficiency

Principle name	Describe
System principle	Comprehensively consider the energy efficiency optimization of base station equipment, network architecture, resource allocation and other aspects to ensure the overall energy efficiency improvement.
Advanced principle	Adopt advanced RF power amplification technology and energy efficiency management means to ensure that the energy efficiency of base stations reaches the leading level in the industry.
Practical principles	The optimization scheme should be feasible and operable in practical application, which is convenient for base station operators to manage and maintain.
Principle of sustainability	The optimization scheme should be conducive to the long-term sustainable development of base stations, reduce energy consumption and operating costs, and improve environmental friendliness.

Radio frequency power amplification technology is one of the key technologies to improve the energy efficiency of small agricultural base stations. By adopting efficient RF power amplifier, optimizing power supply and bias circuit of power amplifier and applying digital predistortion technology, the energy consumption of power amplifier can be reduced and its efficiency can be improved. In addition, the dynamic power control technology can be used to dynamically adjust the output power of the power amplifier according to the real-time load of the base station, so as to optimize the energy efficiency. The application of these technologies will help to improve the overall energy efficiency performance of small agricultural base stations.

In RF circuit design, impedance matching is a crucial link, which affects signal transmission efficiency, power transmission and the performance of the whole system. However, due to the high frequency characteristics of RF signals, traditional discrete components (such as resistors, capacitors and inductors) are often affected by parasitic effects when impedance matching, which leads to performance degradation. Parasitic effects include the parasitic capacitance and inductance of the component itself and the distributed capacitance and inductance on the connecting line. These effects become particularly significant at high frequency, which makes the actual performance of discrete components deviate from the ideal model. In order to overcome these parasitic effects, RF circuit designers usually choose to use distributed parameter components instead of discrete components for impedance matching. The characteristic of distributed parameter components is that their electrical properties are distributed in space, rather than concentrated on one point. In this way, they can better meet the needs of high-frequency signal transmission and reduce the influence of parasitic effects. Microstrip transmission line is a commonly used distributed parameter element, which is widely used in impedance matching in RF circuits. Microstrip line is usually composed of a dielectric substrate and a metal conductor strip attached to it (as shown in Figure 1). By adjusting the width and length of the metal conductor strip and the dielectric constant and thickness of the dielectric substrate, the required impedance matching can be realized.

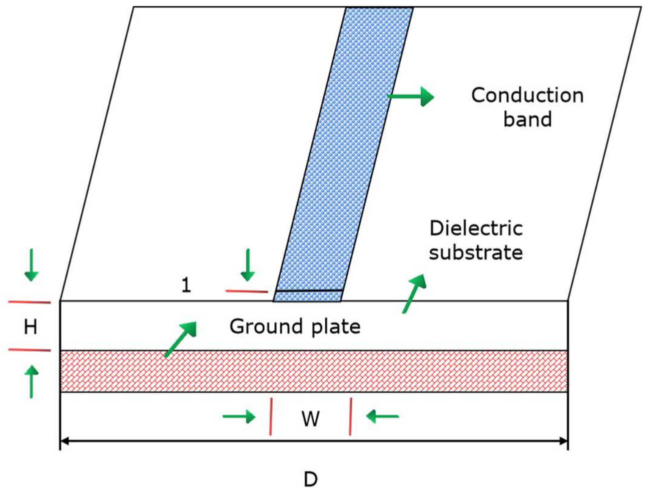

Fig. 1. Structure diagram of microstrip line

According to the required output power and DC bias voltage and referring to the characteristic curve of the device, the output load line of the tube is calculated, so as to determine the real part of the optimal output impedance:

$$R_{\mathrm{L}} = 2(V_b - V_s)I_{\max} \tag{1}$$

where $I_{\max}$ is the maximum drain working current, V_b is the drain-source breakdown voltage, and V_s is the inflection point voltage of the transistor. The output power is:

$$R_{\mathrm{out}} = \left(\frac{1}{2}I_{\max}\right)^2 * R\mathrm{L} = I_{\max}(V_b - V_s) \tag{2}$$

The input can be conjugate matched with small signal S parameters, and can be optimized in RF. Using small signal S parameters to design power amplifier has many remarkable advantages, which brings great convenience to designers. First of all, small signal S parameters are usually easier to obtain, because they are measured in the linear working region of the power tube, and the influence of large signal nonlinear effect does not need to be considered. This enables designers to accurately predict and optimize the performance of the circuit at the early stage of design. Secondly, the small-signal S-parameter design method is relatively simple, and the key indexes such as gain, matching and stability of the power amplifier can be preliminarily designed without complicated mathematical models and simulation tools. This greatly reduces the complexity and difficulty of design and shortens the design cycle. In addition, it is easy to meet the design conditions using small-signal S parameters, because they mainly focus on the small-signal characteristics of power tubes, which are usually not sensitive to the changes of external environment. This enables designers to maintain the consistency of power amplifier performance under different working conditions. The design method of small signal S parameter is easy to realize. Once the preliminary design is completed through the small signal S parameter, the designer can gradually introduce the large signal effect and other nonlinear factors to refine and optimize the circuit according to the actual needs. This method not only ensures the feasibility of the design, but also improves the flexibility of the design.

Energy efficiency is usually defined as the ratio of the workload completed by a system or equipment in a specific time to the total energy consumed. In a communication system, energy efficiency can be expressed as the ratio of total throughput (that is, the total amount of data transmitted) to total power consumption (that is, the total energy consumed by the system). The energy efficiency is the ratio of the lowest total throughput to the total power consumption as follows:

$$\eta_{\mathrm{EE}} = \frac{\mathrm{Throughput}_{\min}}{\mathrm{P}_{\mathrm{total}}} = \frac{\sum_{k=1}^{2} A\lambda_u \mathrm{P}_{\mathrm{covl}}(\gamma_k) R_k}{\sum_{k=1}^{2} A\lambda_k \mathrm{P}_k} \tag{3}$$

where: $\mathrm{Throughput}_{\min}$ stands for the lowest total throughput of the network; $\mathrm{P}_{\mathrm{total}}$ represents the total power consumption of the network; A represents the area of the network; $\mathrm{P}_{\mathrm{covl}}(\gamma_k) R_k$ is the probability that the target user accesses the k layer base station; R_k is the lowest achievable rate after the target user accesses the k layer base station; P_k is the power consumption of each base station in k layer.

Suppose the open access mode is adopted, that is, the target user accesses the base station that can provide the largest signal-to-interference ratio. The probability that the target user accesses the k layer base station is:

$$\mathrm{P}_{\mathrm{cov}}(\gamma_k) = P\left(\bigcup_{x_k = \phi_k} SIR_{xk} > \gamma_k \right) = E\left[1 \bigcup_{x_k = \phi 3_k} SIR_{xk} > \gamma_k \right] \tag{4}$$

When $\gamma_k > 1$, at most only one base station can provide a signal-to-interference ratio greater than γ_k, then:

$$\mathrm{P}_{\mathrm{cov}}(\gamma_k) = E \sum_{x_k = \phi_k} \left[1 SIR_{xk} > \gamma_k \right]^{(a)} = \lambda_k \int_{R^2} P\left(\frac{P_{T_k} h_{x_k} d_{x_k}^{-\alpha}}{I_{x_k}} > \gamma_k \right) d_{x_k}{}^{(a)} \tag{5}$$

$$\lambda_k \int_{R^2} P\left(\frac{P_{T_k} h_{x_k} d_{x_k}^{-\alpha}}{I_{x_k}} > \gamma_k \right) d_{x_k}{}^{(a)} = \lambda_k \int_{R^2} \exp\left(-\frac{\gamma_k I_{x_k} d_{x_k}^{\alpha}}{P_{T_k}} \right) d_{x_k} \tag{6}$$

$$\lambda_k \int_{R^2} \exp\left(-\frac{\gamma_k I_{x_k} d_{x_k}^{\alpha}}{P_{T_k}} \right) d_{x_k} = \lambda_k \int_{R^2} \Gamma_{l_{x_k}}\left(\frac{\gamma_k d_{x_k}^{\alpha}}{P_{T_k}} \right) d_{x_k} \tag{7}$$

When the amplifier works in a linear state, the effective range of input power it can handle is called dynamic range. Once the input power exceeds the upper limit of this range, the output of the amplifier will enter a saturated state; On the contrary, if the input power is lower than the lower limit of this range, the noise will be significantly enhanced and become the main interference factor, as shown in Figure 2. These factors will affect the quality of communication.

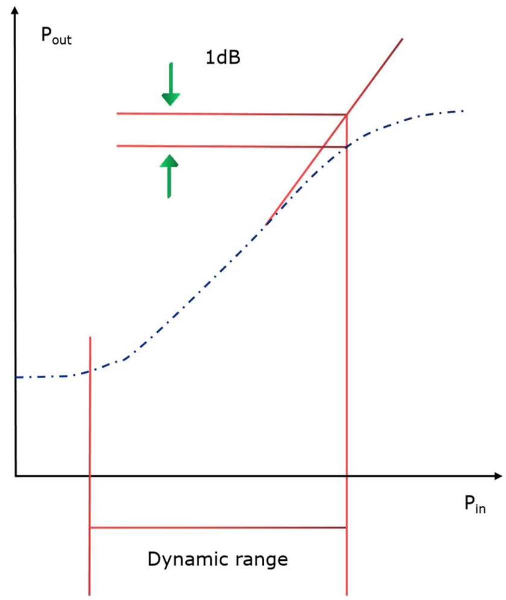

Fig. 2. Schematic diagram of 1dB compression point of amplifier

Efficiency is one of the key indicators in amplifier performance evaluation, which is very important for controlling temperature, improving device reliability and optimizing energy utilization. In amplifiers, efficiency is usually measured by power added efficiency. The formula of power additional efficiency is as follows:

$$\eta_{\text{add}} = \frac{\text{RF output power - RF input power}}{\text{DC input power}} = \frac{P_{out} - P_{in}}{\text{P}_{DC}} \tag{8}$$

Power additional efficiency is defined as the ratio of the difference between output power and input power of amplifier to DC power consumption. Improving the additional efficiency of power means that the amplifier can use electric energy more efficiently and reduce unnecessary energy loss when amplifying the input signal into the output signal. This can not only reduce the operating temperature of the amplifier, thus prolonging its service life and improving its reliability, but also achieve longer battery life or less energy consumption in application scenarios with limited energy, such as mobile communication and satellite communication. In order to improve the additional efficiency of power, various design strategies and technical means can be adopted, including selecting high-performance transistors, optimizing matching network, adopting efficient power management scheme and implementing advanced linearization technology. These measures are helpful to improve the overall performance of the amplifier, so that it can achieve higher energy efficiency ratio while maintaining high linearity and low distortion.

5. Results analysis and discussion

In order to verify the actual effect of the proposed energy efficiency optimization scheme, a simulation experiment platform was built in this study. The platform includes two parts: hardware platform and software platform. The hardware platform uses general wireless communication equipment to simulate the working environment of small agricultural base stations; The software platform uses professional wireless communication simulation software to simulate and analyze the energy efficiency performance of the base station. Through the combined use of these two platforms, the real operating environment of small agricultural base stations can be simulated, and the performance of the proposed energy efficiency optimization scheme can be accurately evaluated. In the simulation experiment, this section sets a series of parameters to simulate the actual working environment. These parameters include wireless communication related parameters such as base station's transmitting power, receiving sensitivity, channel bandwidth, noise power, and energy efficiency related parameters such as equipment's power consumption and efficiency (see Table 3). In order to be closer to the actual situation, these parameters are set reasonably in this experiment with reference to relevant standards and actual measurement data. At the same time, the load and interference factors in different scenarios are also considered to ensure the accuracy and reliability of the simulation results.

Table 3. Parameter setting of simulation experiment

Parameter name	Set value
Receiving sensitivity	-90dBm
Channel bandwidth	10^7Hz
Noise power	-104dBm/Hz
Static power of Macro base station (P_{c1})	1000W
Transmission power of Macro base station (P_{T1})	40W
Static power of micro base stations (P_{C2})	50W
Target SIR of Macro base station (γ_1)	15dB
Target SIR of micro base stations (γ_2)	4dB
User density (λ_u)	0.15m^{-2}
Macro base station density (λ_1)	$10^{-4}m^{-2}$
Road loss index (α)	5

By running the simulation platform and collecting relevant data, the performance results of the proposed energy efficiency optimization scheme in different scenarios are obtained. These results include the changes of energy consumption of base station, efficiency of power amplifier and overall energy efficiency under different load and interference conditions. In order to show the experimental results more intuitively, this section draws corresponding charts and graphs.

The network energy efficiency under different base station density ratios is shown in Figure 3.

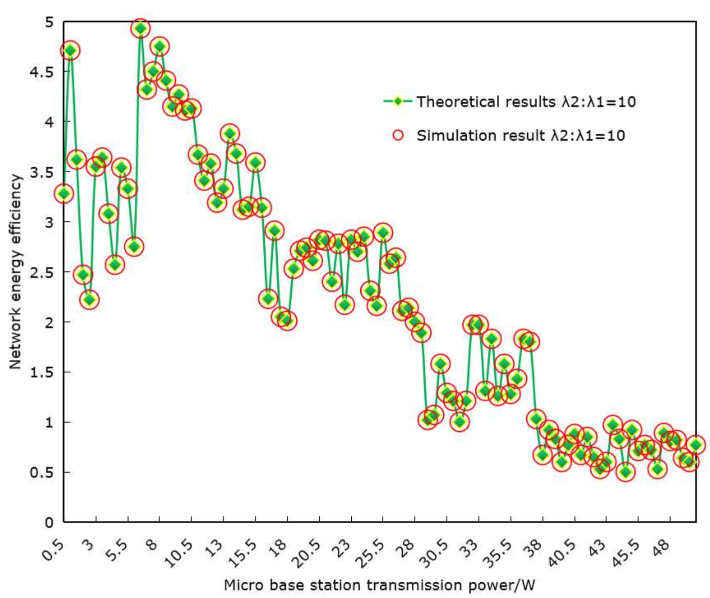

Fig. 3. Network energy efficiency under different base station density ratios

It can be clearly observed from the figure that there is a high degree of consistency between the energy efficiency calculated theoretically and the simulation experimental results. This consistency not only verifies the rationality and accuracy of the simulation experiment setting, but more importantly, it strongly proves the correctness of the energy efficiency expression deduced in this paper. The network energy efficiency under different macro base station densities is shown in Figure 4.

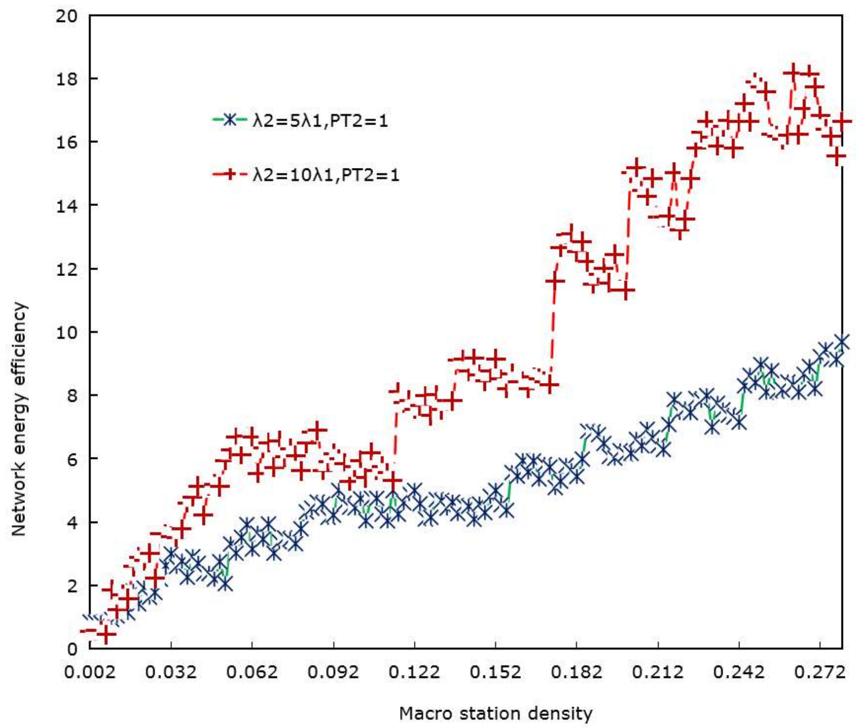

Fig. 4. Network energy efficiency under different macro base station densities

With the increase of macro base station density, the coverage and capacity of the network have been significantly improved, but at the same time, it has also brought higher energy consumption. The optimization algorithm proposed in this paper comprehensively considers network architecture, resource allocation and energy efficiency management, and achieves the goal of reducing energy consumption on the premise of ensuring network performance. Specifically, the optimization algorithm may improve the energy efficiency of the network by adjusting the transmission power of the base station, optimizing the resource allocation strategy and introducing advanced energy efficiency management technology. When the density of macro base station is high, the problem of interference and coverage overlap between base stations is more prominent, and the role of optimization algorithm is more significant. The energy consumption is shown in Figure 5.

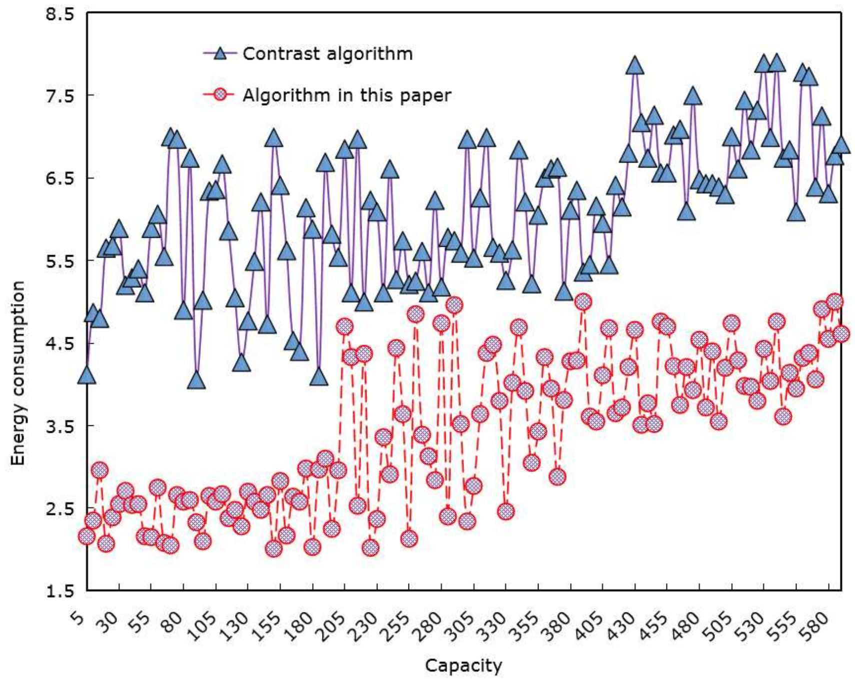

Fig. 5. Energy consumption situation

From the experimental results, it can be seen that compared with the method of maximizing network energy efficiency by adjusting the transmission power of micro-base stations, the proposed method has less energy consumption. This result proves the advantages of this method in reducing energy consumption. The efficiency results of the power amplifier are shown in Figure 6.

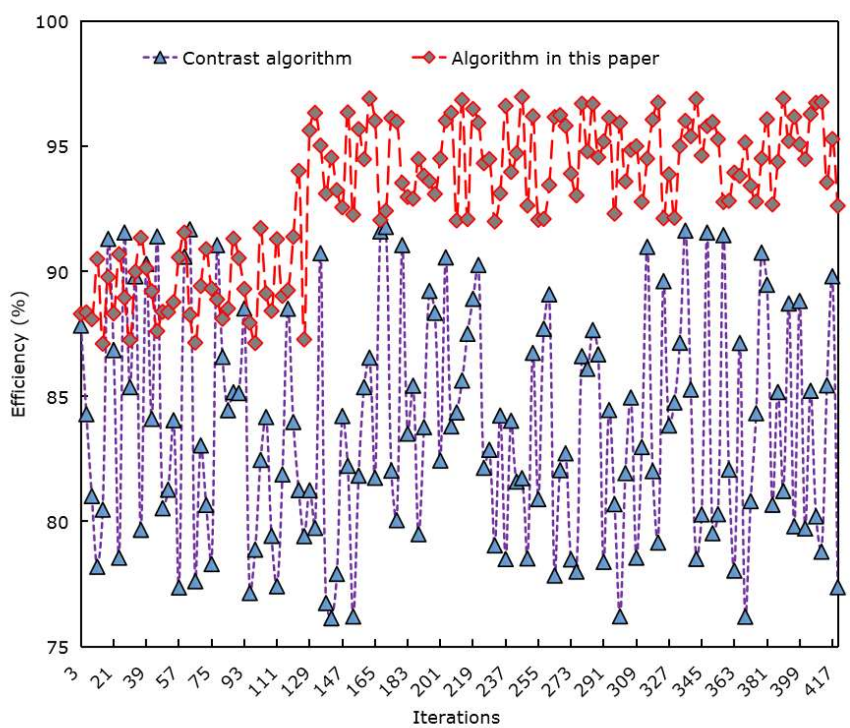

Fig. 6. Efficiency of power amplifier

Experiments show that the power amplifier in this method has high efficiency. This means that the power amplifier in this method can output higher power under the same input power. This high-efficiency power amplifier is helpful to improve the energy efficiency performance of the base station, which further verifies the effectiveness of the method in energy efficiency optimization. The overall energy efficiency and other indicators are shown in Figure 7.

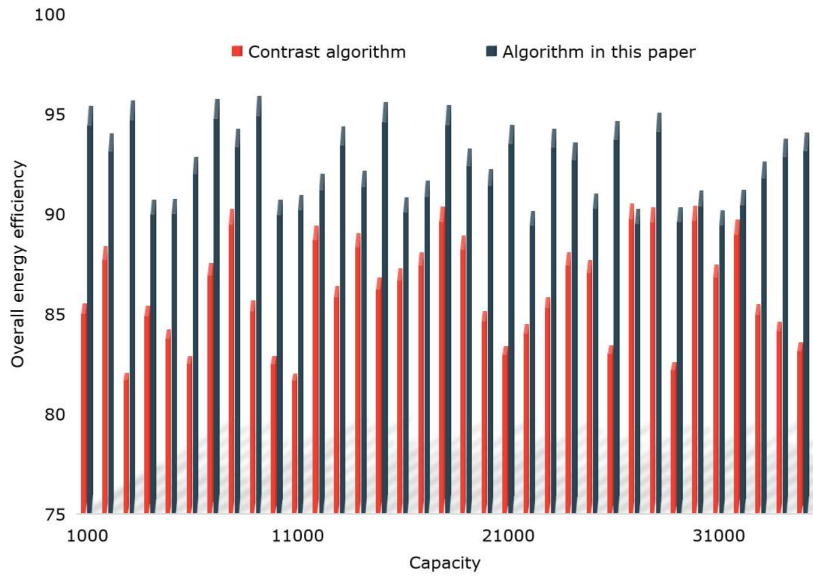

Fig. 7. Overall energy efficiency and other indicators

Experimental results show that compared with the method of maximizing network energy efficiency by adjusting the transmission power of micro-base stations, the overall energy efficiency and other indicators of this method are better. The stability of the algorithm under different loads is shown in Figure 8.

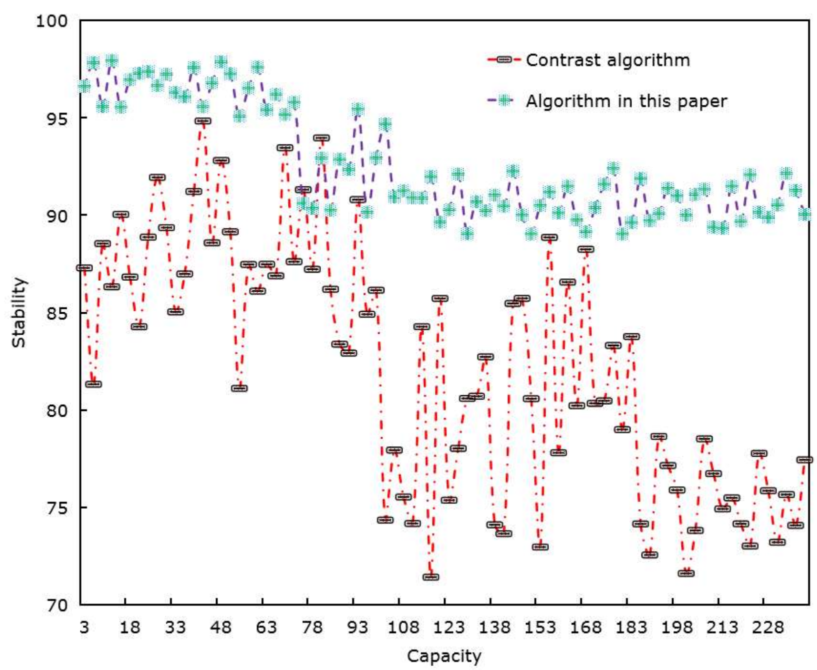

Fig. 8. Algorithm stability

Experiments show that the stability of the algorithm in this paper is considerable under different loads, and even if the load is large, the stability of the method in this paper can reach above 89%. In practical applications, wireless communication systems may face various complicated load situations, so the stability of the algorithm is an important consideration. The excellent stability of this method provides strong support for its popularization and application in practical application.

Through the analysis and discussion of the simulation results, it is found that the proposed energy efficiency optimization scheme can significantly reduce the energy consumption of the base station and improve the energy efficiency performance in different scenarios. Specifically, in the light load scenario, the optimization scheme can reduce energy consumption by reducing the output power of the power amplifier and dynamically adjusting the resource allocation; In the heavy load scenario, the optimization scheme can improve the energy efficiency performance by improving the efficiency of the power amplifier and optimizing the resource scheduling algorithm. In addition, it is found that the proposed scheme is robust to interference factors and can resist the influence of interference on the energy efficiency of base stations to some extent. These results prove the effectiveness and superiority of the proposed energy efficiency optimization scheme. Although the effectiveness and superiority of the energy efficiency optimization scheme are verified by simulation experiments, there are still some limitations. For example, the simulation environment may be too idealistic to fully reflect the complexity of the real network environment; At the same time, experimental parameter setting and scene selection may also affect the universality of the results. In addition, other performance indicators, such as network throughput, delay, etc., are not fully considered when evaluating energy efficiency, and the simulation results may only reflect short-term energy efficiency performance. Finally, although the scheme shows its effectiveness in different scenarios, its universality and resistance to complex interference factors need to be further verified.

6. Conclusions

In this paper, the energy efficiency of agricultural small base stations in Aksu area is deeply analyzed and studied, and an energy efficiency optimization scheme based on RF power amplification is put forward. The effectiveness and superiority of the proposed scheme are verified by simulation experiments and practical applications. The research work not only provides a feasible energy efficiency improvement scheme for agricultural small base stations in Aksu area, but also provides a useful reference for the energy efficiency optimization of wireless communication equipment.

The main results of this study include: The energy efficiency optimization scheme of agricultural small base station based on RF power amplification is proposed. A simulation platform is built and the effectiveness of the proposed scheme is verified. In practical application, it has achieved remarkable energy-saving effect and improved the energy efficiency performance of the base station. These achievements have important contributions and significance for promoting the energy efficiency improvement and green development of wireless communication equipment. With the continuous development of wireless communication technology and the increasing application demand, the energy efficiency requirements for wireless communication equipment will be higher and higher in the future. Therefore, it is suggested that future research work should continue to focus on the energy efficiency optimization of wireless communication equipment and explore more innovative technologies and methods to improve the energy efficiency performance of equipment. At the same time, it is also hoped that the government and relevant departments can increase their support and investment in energy efficiency optimization of wireless communication equipment to promote the green development and sustainable development of the industry.

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Data Availability

All data generated or analysed during this study are included in this published article.

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References

[1] Yang, Z., Chen, M., Saad, W., Hong, C. S., & Shikh-Bahaei, M. (2020). Energy efficient federated learning over wireless communication networks. IEEE Transactions on Wireless Communications, 20(3), 1935-1949.

[2] Akpakwu, G. A., Silva, B. J., Hancke, G. P., & Abu-Mahfouz, A. M. (2017). A survey on 5G networks for the Internet of Things: Communication technologies and challenges. IEEE access, 6, 3619-3647.

[3] Nawaz, H., Ali, H. M., & Laghari, A. A. (2021). UAV communication networks issues: A review. Archives of Computational Methods in Engineering, 28(3), 1349-1369.

[4] Zhang, Z., Wen, F., Sun, Z., Guo, X., He, T., & Lee, C. (2022). Artificial intelligence-enabled sensing technologies in the 5G/internet of things era: from virtual reality/augmented reality to the digital twin. Advanced Intelligent Systems, 4(7), 2100228.

[5] Hazarika, A., & Rahmati, M. (2023). Towards an evolved immersive experience: Exploring 5G-and beyond-enabled ultra-low-latency communications for augmented and virtual reality. Sensors, 23(7), 3682.

[6] Lv, Z., Lloret, J., & Song, H. (2020). Internet of Things and augmented reality in the age of 5G. Computer Communications, 164, 158-161.

[7] Savcı, H. Ş., Türk, B. B., Hürcan, F., & Dogan, H. (2024). A Compact GaN Power Amplifier Module for New Generation Cellular Basestations. Black Sea Journal of Engineering and Science, 7(3), 587-593.

[8] Kebede, T., Wondie, Y., Steinbrunn, J., Kassa, H. B., & Kornegay, K. T. (2022). Multi-carrier waveforms and multiple access strategies in wireless networks: performance, applications, and challenges. IEEE Access, 10, 21120-21140.

[9] Alimi, I. A., Teixeira, A. L., & Monteiro, P. P. (2017). Toward an efficient C-RAN optical fronthaul for the future networks: A tutorial on technologies, requirements, challenges, and solutions. IEEE Communications Surveys & Tutorials, 20(1), 708-769.

[10] Ahmed, F., Naeem, M., & Iqbal, M. (2017). ICT and renewable energy: a way forward to the next generation telecom base stations. Telecommunication Systems, 64, 43-56.

[11] Ramella, C., Piacibello, A., Quaglia, R., Camarchia, V., & Pirola, M. (2017). High efficiency power amplifiers

for modern mobile communications: The load-modulation approach. Electronics, 6(4), 96.

[12] Alsharif, M. H., Kim, J., & Kim, J. H. (2017). Green and sustainable cellular base stations: An overview and future research directions. Energies, 10(5), 587.

[13] Quaglia, R., & Cripps, S. (2017). A load modulated balanced amplifier for telecom applications. IEEE Transactions on Microwave Theory and Techniques, 66(3), 1328-1338.

[14] Hamza, K. H., & Nirmal, D. (2020). A review of GaN HEMT broadband power amplifiers. AEU-International Journal of Electronics and Communications, 116, 153040.

[15] Yamanaka, K., Shinjo, S., Komatsuzaki, Y., Sakata, S., Nakatani, K., & Yamaguchi, Y. (2021). Overview and prospects of high power amplifier technology trend for 5G and beyond 5G base stations. IEICE Transactions on Electronics, 104(10), 526-533.

[16] Shah, B., Dalwadi, G., Shah, H., & Kothari, N. (2022). Cost-optimized energy-efficient power amplifier for TD-LTE outdoor pico base station. IETE Journal of Research, 68(2), 1366-1375.

[17] Hussein, S., & Yassin, M. (2022). Efficiency enhancement of CMOS power amplifier for RF applications. Al-Rafidain Engineering Journal, 27(2), 60-67.

[18] Vasjanov, A., & Barzdenas, V. (2018). A review of advanced CMOS RF power amplifier architecture trends for low power 5G wireless networks. Electronics, 7(11), 271.

[19] Lahiry, A., Le, K. N., Bao, V. N. Q., & Tam, V. W. (2022). Analytical evaluation of power-amplifier-based charging methodology and energy efficiency optimization framework for aerial base stations. IEEE Transactions on Aerospace and Electronic Systems, 58(5), 4451-4472.