Journal of Electronic Research and Application, 2024, Volume 8, Issue 4
http://ojs.bbwpublisher.com/index.php/JERA
ISSN Online: 2208-3510
ISSN Print: 2208-3502

Research on Integrated Communication Perception Technology Based on RIS Assistance

Hao Yang*, Chuanjiang Wang, Xiaoyi Li, Qi Xiang, Taoyong He

Wuhan Ruisi Communication Technology Co., Ltd., Wuhan 430000, Hubei Province, China

***Corresponding author:** Hao Yang, dspyang@163.com

Abstract: Reconfigurable Intelligent Surface (RIS) assisted communication perception integration technology is an emerging communication technology that introduces reconfigurable intelligent surfaces in the communication environment to achieve real-time perception and control of signals, thereby improving the performance and efficiency of communication systems. This article studies the integrated communication perception technology assisted by RIS, including system principles, key technologies, and performance analysis. Through literature review and analysis of relevant research, the potential application prospects of this technology in future communication systems have been revealed.

Keywords: RIS-assisted communication; Perception integration; Reconfigurable intelligent surfaces; Performance analysis; Application prospects

Online publication: August 12, 2024

1. Introduction

The integrated communication perception technology assisted by RIS is an innovative method that introduces Reconfigurable Intelligent Surface (RIS) based on traditional wireless communication systems to improve communication performance. This technology achieves intelligent control of signal perception, reflection, and transmission by deploying a large number of RIS components in the communication environment and utilizing their controllable phase or amplitude characteristics, thereby optimizing signal quality, enhancing system capacity, and suppressing interference. RIS, as an intelligent surface with a reflection function, can change the propagation path and interference situation of the signal by adjusting the phase and amplitude of the reflected signal, thereby offsetting signal fading, reducing multipath interference, and improving signal reception quality and reliability. This intelligent regulation capability makes RIS an ideal choice for dealing with complex channel environments. By intelligently regulating the reflected signals on RIS, optimization strategies such as signal beamforming, elimination of multi-user interference, and spatial frequency multiplexing can be achieved, greatly improving the system's capacity and spectral efficiency. This flexible resource allocation method makes it possible for multiple users to transmit simultaneously, greatly enhancing the system's throughput and coverage. RIS can suppress and isolate interference by sensing surrounding interference signals and intelligently regulating their reflected signals. The ability to manage interference can significantly improve the anti-interference performance of the system, enabling wireless communication systems to maintain good communication quality even in high-density users and complex interference environments.

2. Overview of traditional communication perception technology

2.1. Definition and basic principles of communication perception

Communication perception is a technology that obtains information about channel status, interference conditions, user location, and movement by perceiving and analyzing various parameters and features in the wireless communication environment [1]. It is an important technological means that can provide real-time information about the communication environment to support the optimization and decision-making of wireless communication systems.

The basic principle of communication perception is to receive and process signals from wireless channels and use the characteristics and parameters of the signals to obtain information about the communication environment. This information can include channel fading, signal-to-noise ratio, channel capacity, spectrum usage, interference sources and types, user location and movement speed, etc. Communication perception can be achieved through various technical means, including channel estimation, spectrum sensing, position sensing, and so on [2].

In terms of channel perception, communication systems can use the received signal to estimate the characteristics of the channel, such as fading, multipath propagation, etc. By perceiving the channel state, the system can adopt corresponding modulation methods, power control strategies, and beamforming techniques to improve communication quality and system performance.

In terms of spectrum sensing, communication systems can obtain information on available spectrum resources by monitoring and analyzing spectrum usage [3]. This is crucial for technologies such as dynamic spectrum access, spectrum sharing, and cognitive radio to improve spectrum utilization efficiency and address spectrum resource shortages.

In terms of interference perception, communication systems can obtain information on interference sources and types by monitoring and analyzing interference signals in wireless communication systems. This helps to implement strategies such as interference suppression, interference localization, and interference management to improve the performance and reliability of communication systems.

In terms of location perception, communication systems can use information such as the time, angle, and power of the received signal to obtain the user's location and movement situation. This is crucial for applications such as wireless positioning, location services, and mobile management, as it can provide precise location information support [4].

2.2. Classification and characteristics of traditional communication perception technologies

Traditional communication perception technology can be classified based on its application field and target, mainly including channel perception, spectrum perception, interference perception, and position perception. These technologies play an important role in wireless communication systems, providing critical information support for system optimization and performance improvement [5].

Channel perception refers to obtaining information about channel status by receiving and analyzing signals. It can be used in applications such as adaptive modulation, power control, beamforming, etc. to improve communication quality and system capacity. The characteristic of channel perception is the need to accurately estimate channel characteristics, which requires high requirements for signal sampling and processing.

Spectrum perception refers to obtaining information on available spectrum resources through monitoring and analyzing spectrum usage. It can be used in technologies such as dynamic spectrum access, spectrum sharing, and cognitive radio to improve spectrum utilization efficiency and solve the problem of spectrum resource shortage. The characteristic of spectrum perception is the need to monitor and analyze spectrum usage in real-time, and accurately identify available spectrum resources.

Interference perception refers to obtaining information on interference sources and types by monitoring and analyzing interference signals in wireless communication systems [6]. It can be used in applications such as interference suppression, interference localization, and interference management to improve the performance and reliability of communication systems. The characteristic of interference perception is the need to accurately identify and analyze interference signals, and adopt corresponding interference processing strategies.

Location perception refers to obtaining the user's position and movement situation by utilizing information such as time, angle, and power of the received signal. It can be used in applications such as wireless positioning, location services, and mobile management to provide users with precise location information support. The characteristic of location awareness is the need to accurately determine the user's location and be able to track their movement in real-time. The characteristic of traditional communication perception technology is to obtain information related to the communication environment through the reception and processing of wireless signals.

This information can be used to optimize system parameters, improve communication quality, enhance spectrum utilization efficiency, and solve interference problems [7]. However, traditional communication perception techniques are often limited by the accuracy of sensors, limitations in computing resources, and the impact of complex channel environments. To overcome these limitations, new perception technologies and algorithms continue to emerge, such as machine learning-based perception technology and distributed perception technology, to improve the accuracy and efficiency of perception [8].

2.3. Analysis of the advantages and disadvantages of traditional communication perception technology

Traditional communication perception technology plays an important role in wireless communication systems, helping to optimize resource allocation, power control, and interference management, thereby improving system capacity and coverage. By perceiving changes in the wireless communication environment, traditional communication perception techniques can achieve adaptive adjustment of the system to adapt to different channel conditions and interference situations. One of the advantages of traditional communication perception technology is that it can provide detailed information about the communication environment, providing a basis for system decision-making and optimization [9]. For example, spectrum sensing can help to understand the distribution of available spectrum resources, thereby achieving dynamic spectrum access and spectrum sharing. Interference perception can identify interference sources and adopt corresponding interference management strategies to improve the system's anti-interference performance. Wireless positioning and positioning services can be achieved through location awareness to meet the requirements of location-related applications.

However, traditional communication perception technologies also have some drawbacks. Firstly, traditional communication perception technologies typically require a large amount of computation and signal processing, which places high demands on the system's computation and energy consumption [10]. This may lead to application limitations in resource-limited devices or networks. Secondly, the performance of traditional communication perception technologies is limited by the performance of hardware devices and sensors, such as the sensitivity and spectral resolution of receivers. This may limit the accuracy and reliability of perception. Finally, traditional communication perception technologies require processing and analysis of a large amount of perception data, posing challenges to data processing and privacy protection. In the process of data collection, transmission, and storage, it is necessary to consider the security and privacy protection of data. Further research and innovation are needed to overcome its shortcomings and challenges, improve perception accuracy, reduce energy consumption, improve data processing and privacy protection performance, and meet the growing demands of communication and application scenarios.

3. Overview of RIS technology

3.1. The basic and working principle of RIS

RIS is a surface composed of a large number of passive components that can precisely manipulate electromagnetic waves by adjusting the reflection and transmission characteristics of the components. The basic principle of RIS is to use the adjustable reflection coefficient on the component to change the propagation characteristics of electromagnetic waves. RIS consists of many small units, each of which can control the amplitude and phase of reflected waves by adjusting their phase and amplitude, thereby achieving precise control of propagating waves. The working principle of RIS can be simply described as the following steps:

(1) Receiving stage: RIS receives signals from transmitters, usually transmitted through antennas or base stations.

(2) Reflection regulation: Each unit in RIS adjusts its reflection coefficient and changes the amplitude and phase of the propagating wave based on a predetermined algorithm and regulation strategy.

(3) Propagation stage: The regulated wave is reflected by RIS and propagates along a specific path to the target receiver, forming a channel that affects signal transmission.

3.2. Potential application of RIS in communication systems

RIS technology has broad application potential in communication systems, which can significantly improve the performance and resource utilization efficiency of communication systems. The following are some of the main applications of RIS in communication systems:

(1) Channel gain enhancement: RIS can focus or merge signals during propagation by adjusting the amplitude and phase of reflected waves, enhancing the energy of signals at specific positions, thereby improving channel gain and coverage range.

(2) Beamforming: RIS can adjust the phase and amplitude of reflected waves based on the position and communication requirements of the receiver, achieving precise beamforming. This improves signal directionality and reception quality.

(3) Multi-user interference management: RIS can effectively suppress and manage interference between multiple users by adjusting the phase and amplitude of reflected waves, improving system capacity and performance.

(4) Spectrum resource optimization: RIS can dynamically adjust the frequency response of reflected waves to achieve dynamic allocation and sharing of spectrum resources, improving spectrum utilization efficiency and system capacity.

(5) Security and privacy enhancement: RIS can achieve information protection and privacy enhancement by adjusting the characteristics of reflected waves, and resisting eavesdropping and attack behavior.

3.3. Comparative analysis of RIS technology and traditional communication perception technology

Compared with traditional communication sensing technology, RIS technology has the following advantages and characteristics:

(1) Accuracy and flexibility: RIS can accurately control the amplitude and phase of propagating waves, providing more precise and flexible transmission control, while traditional communication sensing technology is usually limited by hardware and environmental conditions.

(2) Resource efficiency: RIS can perform signal processing and control at the receiver end, while traditional communication sensing technologies typically require processing at the base station or central controller, saving communication resources and energy consumption.

(3) Real-time performance: RIS can adjust the characteristics of reflected waves in real time to adapt to dynamic communication environment changes, while traditional communication perception technologies usually require periodic sampling and processing, which cannot respond to environmental changes in real-time.

(4) Cost-effectiveness: RIS consists of a large number of passive components, which have lower costs and energy consumption compared to the active devices and sensors required in traditional communication perception technologies.

However, RIS technology also has some challenges and limitations:

(1) Complexity: The design and implementation of RIS involve a large number of components and algorithms, which require addressing technical issues such as phase modulation, power consumption, and computational complexity.

(2) Communication system integration: The introduction of RIS requires close integration and optimization with existing communication systems to achieve optimal performance and interoperability.

(3) Feasibility and scalability: The feasibility and scalability of RIS technology in practical applications still need further research and verification, especially in large-scale deployment and real-time control.

4. Performance analysis of RIS-assisted communication perception integration technology

4.1. System performance evaluation indicators and methods

For the performance evaluation of RIS-assisted communication perception integration technology, the following indicators and methods are usually used for evaluation:

(1) Signal quality: The performance of the communication system largely depends on the quality of the received signal. Common indicators include signal-to-noise ratio (SNR), bit error rate (BER), and channel capacity. These indicators can evaluate whether the signal quality has been improved after RIS regulation.

(2) Energy efficiency: Energy efficiency measures the ratio of the energy consumed by a communication system during data transmission to the effective information transmitted. By comparing the energy efficiency of RIS-assisted communication perception integration technology with traditional communication systems, the improvement effect of RIS on energy utilization can be evaluated.

(3) System capacity: System capacity refers to the maximum number of users or data throughput that a communication system can carry. By utilizing the ability of RIS to regulate reflected waves, the transmission characteristics of the channel can be improved, thereby increasing system capacity.

(4) Interference management: RIS technology can manage and suppress interference between multiple users by adjusting the phase and amplitude of reflected waves. By evaluating the performance of RIS-assisted communication perception integration technology in interference management, the improvement effect on system performance can be determined.

4.2. Performance analysis model of RIS-assisted communication perception integration technology

To conduct performance analysis, researchers usually establish a performance analysis model based on RIS-assisted communication perception integration technology. These models are typically based on methods such as probability theory, information theory, and communication theory, combined with the characteristics of RIS and system parameters for modeling [11]. The following are some common performance analysis models:

(1) Signal transmission model: This model describes the signal transmission process from the transmitter to the receiver, considering the reflection and transmission characteristics of RIS. Modeling can be done using geometric optics, vector transmission theory, and other methods.

(2) Channel capacity model: This model is used to evaluate the improvement effect of RIS-assisted communication perception integration technology on channel capacity. The capacity formula in information theory can be used to model RIS considering factors such as reflection gain and transmission loss.

(3) Interference management model: This model is used to evaluate the performance of RIS technology in interference management. We can consider the interference relationship between multiple users and model it using methods such as interference matrix and interference elimination.

4.3. Discussion on simulation experiments and performance analysis results

To verify the performance of RIS-assisted communication perception integration technology, researchers usually conduct simulation experiments and conduct performance analysis based on the above performance evaluation indicators and models. Through simulation experiments, the performance results of RIS technology can be obtained in different scenarios and parameters, and compared with traditional communication systems. In the discussion of performance analysis results, quantitative analysis and comparison can be conducted on different performance indicators. For example, by plotting the curves of SNR and BER, the improvement effect of RIS technology on signal quality can be evaluated. By comparing the curve of system capacity with the number of users, the effect of RIS on increasing system capacity can be evaluated. Additionally, the performance of RIS can be discussed under different operating frequency bands, number and position of reflective elements, and their impact on system performance can be analyzed. The discussion of performance analysis results can also be further explored for different application scenarios and system requirements. For example, in mobile communication, the improvement effect of RIS technology on the coverage range and mobile performance of mobile users can be discussed. In indoor communication, the suppression effect of RIS technology on signal fading and multipath effects, as well as the improvement effect on indoor coverage and capacity, can be evaluated [12].

5. Conclusion

Communication perception, as a key technology, provides real-time environmental information for wireless communication systems by perceiving and analyzing various parameters and features in the wireless communication environment, thereby supporting system optimization and decision-making. Traditional communication sensing technologies include channel sensing, spectrum sensing, interference sensing, and position sensing, which play important roles in adaptive modulation, power control, beamforming, dynamic spectrum access, spectrum sharing, interference suppression, interference localization, wireless localization, and more. Nonetheless, traditional perception technologies face challenges such as accuracy limitations, computational resource limitations, and complex channel environments. With the continuous development of technology, new perception technologies and algorithms continue to emerge, such as machine learning-based perception technology and distributed perception technology, to improve the accuracy and efficiency of perception. These new technologies have brought new opportunities and challenges to the development of communication perception. Through further research and innovation, communication perception technology will provide stronger and more reliable support for performance optimization, spectrum resource utilization, and interference management of wireless communication systems.

Disclosure statement

The authors declare no conflict of interest.

References

[1] Zhang J, Li H, Zhang H, 2017, Spectrum Sensing Techniques in Cognitive Radio Networks: A Survey. Wireless Personal Communications, 97(1): 1–26.

[2] Zhao C, Jiang H, 2018, Joint Sensing and Access in Cognitive Radio Networks: A Survey. IEEE Communications Surveys and Tutorials, 20(2): 1067–1091.

[3] Chen X, Hossain E, Leung VC, 2019, Interference Sensing and Management in 5G and Beyond: Recent Advances and Future Trends. IEEE Communications Magazine, 57(7): 52–59.

[4] Wang C, Li Y, Zhang W, 2020, Machine Learning-Based Spectrum Sensing in Cognitive Radio Networks: A Survey. IEEE Access, 8: 192861–192875.

[5] Li Y, Liang YC, Shen X, 2021, From Cognitive Radio to Intelligent Radio: A Comprehensive Survey. IEEE Communications Surveys and Tutorials, 23(1): 3–35.

[6] Tang J, Gao X, Li GY, 2021, Distributed Spectrum Sensing for Cognitive Radio Networks: A Survey. IEEE Communications Surveys and Tutorials, 23(1): 36–54.

[7] Zeng T, Cai Y, Zhang J, et al., 2024, Research on Key Technologies and System Architecture for 6G Communication Perception Integration. Wireless Communication Technology, 2024(03): 59–66.

[8] Yang J, Li M, Zhang S, 2024, Research on Integrated Communication Perception Technology Based on RIS Assistance. Wireless Communication Technology, 50(02): 334–341.

[9] Wang Q, Xing Y, Fan W, et al., 2023, Research on Key Technologies of 6G Core Network Supporting Communication Perception Integration. Electronic Technology Applications, 49(12): 50–55.

[10] Yang X, 2023, Key Technology Design and Implementation of Perception Integration System for 6G Communication. Electronic Manufacturing, 31(16): 81–83 + 96.

[11] Wang J, 2023, Key Technology Research on Wireless Communication Perception Integrated Waveform, thesis, Zhejiang University of Business and Technology.

[12] Wang Y, Jin J, Lou M, et al., 2022, Key Technologies and Applications of Communication Perception Integration. Communication World, 2022(21): 27–30.