Research on Radar Communication Integration System Based on Orthogonal Frequency Division Multiplexing

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Abstract: Orthogonal Frequency Division Multiplexing (OFDM) is a kind of MCM Multi-CarrierModulation, the main idea is to divide the channel into a number of orthogonal sub-channels, and convert the high-speed data signal into parallel low-speed sub-data streams. Modulated to be transmitted on each subchannel, OFDM has become an important technology in the field of modern wireless communication by virtue of its high spectral efficiency and strong anti-interference capability. In order to comply with the current research hotspot, this paper discusses the application of OFDM in Joint Radar and Communication (JRC) system, and proposes an optimization design method based on the analysis of performance indexes and typical algorithms of OFDM in JRC system. Simulation results show that the system with this method has good robustness in multipath interference and noise environment.

Keywords: Orthogonal frequency division multiplexing; Radar communication integration; Anti-jamming; High spectrum

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In recent years, with the rapid development of wireless communication and radar technology, spectrum resources are becoming increasingly tight, and the Joint Radar and Communication (JRC) system has become a research hotspot.The JRC system aims to realize the collaborative work of radar detection and data transmission through the same waveform, which significantly improves the efficiency of the spectrum and the utilization of resources. Orthogonal Frequency Division Multiplexing (OFDM), as a multicarrier modulation technique with high spectral efficiency, strong anti-jamming capability and robustness in multipath environment, is widely used in wireless communication systems and JRC research. data transmission and effectively separates radar and communication signals. However, the application of OFDM in JRC systems faces technical challenges such as high peak-to-average power ratio (PAPR), complex channel estimation, and ambiguous radar signals. Therefore, how to optimize OFDM performance in JRC systems to meet the demands of multiuser and dynamic channel environments has become a core issue in current research.

1. Modeling and Parameterization of OFDM in JRC Systems

OFDM technology significantly enhances the system's resistance to multipath fading by decomposing the high-speed data stream into multiple narrowband subcarriers for transmission, so that the signal from each subcarrier is transmitted in an approximately flat narrowband channel. This feature makes OFDM particularly suitable for JRC systems, which can simultaneously support radar detection and communication transmission

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requirements. Specifically, the signaling model of the JRC system can be expressed as follows:

$$s(t)=\sum_{k=0}^{N-1} X_k\, e^{j2\pi f_k t}$$

where N is the number of subcarriers and X_k represents the modulation symbol on each subcarrier, and f_k is the subcarrier frequency. The subcarriers are orthogonal to each other so that they can occupy adjacent frequency bands without interfering with each other, which greatly improves the spectrum utilization.The response of OFDM system in a wireless channel can be expressed as:

$$H(f)=\sum_{l=0}^{L-1} h_l\, e^{-j2\pi f\tau_l}$$

Of these, the h_l and τ_l denote the gain and delay of the lth path, respectively. In order to make OFDM systems operate stably even in multipath environments, Cyclic Prefix (CP) is usually introduced to eliminate Inter-Symbol Interference (ISI). The selection of the length of the cyclic prefix is particularly important, because too short a CP may lead to multipath interference, while too long a CP will waste spectral resources and reduce spectral efficiency.

In the parameter design, the number of subcarriers N, the symbol period T and the cyclic prefix length need to be considered comprehensively to balance the delay and spectral efficiency of the system. For example, increasing the number of subcarriers N can effectively improve the spectrum utilization, but at the same time, it will also increase the peak-to-average power ratio (PAPR) of the system, leading to higher nonlinear distortion. Therefore, in system design, parameter configurations need to be combined with specific transmission scenarios to ensure that the JRC system achieves optimal performance in realizing the dual functions of radar detection and data communication.

2. PAPR Suppression Method for OFDm Signals

Since OFDM uses multicarrier modulation, its signal peaks tend to be much higher than the average value, resulting in a high peak-to-average power ratio (PAPR). A high PAPR not only introduces nonlinear distortion, but also increases the design difficulty of the power amplifier and seriously affects the transmission efficiency of the system. Therefore, PAPR suppression is crucial in JRC system design.

To cope with this problem, this paper adopts the Clipping Noise Compression (CNC) method and proposes an improved CNC-IAF scheme by combining with Airy Function.PAPR is defined by Eq:

$$PAPR=\frac{max(|x(t)|^2)}{E[|x(t)|^2]}$$

where $max(|x(t)|^2)$ is the peak power of the signal, and $E[|x(t)|^2]$ is the average power of the signal. In the CNC-IAF scheme, the Airy function is used for limiting high amplitude signals, and its smoothing characteristic can effectively reduce the noise distortion caused by limiting. Specifically, the introduction of Airy's function can not only suppress the PAPR, but also maintain a low BER under the premise of low complexity, which improves the value of the application in the JRC system.

Simulation results show that the CNC-IAF method is better than the traditional limiting processing scheme in PAPR suppression, and at the same time can effectively control the BER of the system, which provides an efficient means of PAPR suppression for the JRC system, and enables the system to realize the dual functions of radar and communication with good transmission stability and anti-jamming capability at the same time.

3. Deep Learning Based OFDM Channel Estimation

Under conditions of high multipath fading and noise interference, OFDM receivers require accurate channel estimation to ensure high-quality demodulation of data. Traditional channel estimation algorithms, such as least squares (LS) and minimum mean square error (MMSE), often have insufficient performance in complex wireless environments, while deep learning methods can effectively adapt to dynamic channel conditions. For this reason, this paper adopts a model-driven deep learning channel estimation method, constructs the FBLTNet model, and combines Bi-LSTM and Transformer-encoder for enhancing the accuracy and robustness of channel estimation.

The FBLTNet model is mainly divided into two parts: channel estimation and signal detection.Bi-LSTM is used to capture the sequential characteristics of the channel over time, while the Transformer-encoder enhances the network for long time dependence in channel detection. This channel estimation process can be represented as:

$$\hat{H} = \mathrm{Transformer}(\text{Bi-LSTM}(Y))$$

where $\hat{H}$ is the estimated channel matrix, and Y is the received signal. Bi-LSTM The dynamic features of the received signal in the time domain are captured, and subsequently the signal features are deeply encoded by the Transformer to accomplish accurate channel estimation. Compared to the traditional interpolation-based channel estimation methods, FBLTNet is more adaptable in nonlinear and nonsmooth channels.

Simulation results show that the bit error rate (BER) of the FBLTNet model is significantly lower than that of the conventional algorithm under Rayleigh fading channels, while the convergence speed is improved by about 25% compared to the data-driven algorithm. In addition, FBLTNet substantially improves the stability of channel estimation with relatively low system complexity compared to conventional methods.

4. Fuzzy Deconvolution Method Based on OFDM-LFM Signals

In the integrated radar communication (JRC) system, pulsed Doppler radar faces the problem of distance ambiguity and velocity ambiguity. To accurately detect the target distance and velocity information, the distance-velocity coupling problem needs to be overcome. In this paper, an ambiguity lifting method based on orthogonal frequency division linear frequency modulation (OFDM-LFM) signals is proposed.The OFDM-LFM signals achieve high resolution of the signals in both frequency and time domains by combining orthogonal frequency division multiplexing (OFDM) and linear frequency modulation (LFM) with stronger resistance to Doppler frequency shift and multipath interference.

In order to further improve the signal defuzzification effect, this paper designs a data rearrangement echo processing method, so that the echo signal is no longer overlapped with the distance and speed information after processing. The fuzzy function of the radar system is defined as:

$$\chi(\tau, \nu) = \int s(t)s^*(t-\tau)e^{-j2\pi\nu t}dt$$

where τ is the time delay, and ν is the Doppler frequency shift. Simulation shows that the fuzzy function map exhibits the characteristics of clear main flap and significant side flap suppression after using OFDM-LFM signal processing, which effectively separates the coupling information of distance and velocity.

Further simulation results verify the superiority of OFDM-LFM signals in terms of distance resolving power and velocity estimation accuracy. In echo signal processing, the JRC system using OFDM-LFM is able to outperform the conventional pulsed radar signal processing method in terms of distance resolving power and target velocity estimation accuracy.

5. PAPR Optimization in Multi-User MIMO-OFDM

In multiuser MIMO-OFDM systems, signals from multiple users are simultaneously transmitted in the same frequency band, which is prone to interference and high peak average power ratio (PAPR) problems. High PAPR leads to nonlinear distortion of the power amplifier, which affects the signal quality and system stability. For this reason, in this paper, Accelerated Proximal Gradient Method (APGM) is used to optimize the downlink PAPR of multiple-input multiple-output (MIMO) systems, which improves the power control efficiency as well as the transmission performance.

The algorithm considers the PAPR suppression problem and signal transmission optimization as a joint optimization problem with an objective function:

$$min\frac{1}{2}\parallel Ax-b\parallel^2+\lambda\parallel x\parallel_1$$

where A denotes the transmission matrix, x is the optimized signal vector, and λ is a regularization parameter to balance the error term and the PAPR suppression term. This optimization problem is solved iteratively by an accelerated proximal gradient algorithm, which updates the signal amplitude and phase at each iteration to gradually reduce the PAPR while maintaining the signal quality of the system.

Simulations show that the APGM algorithm is able to significantly reduce the PAPR and effectively minimize the nonlinear distortion of the power amplifier in a multiuser MIMO-OFDM system. Compared with the traditional algorithm, the APGM algorithm has faster convergence speed, lower computational complexity, and significant improvement in transmission quality.

6. Simulation and Analysis

In this paper, extensive simulation tests are conducted in MATLAB environment to evaluate the practical performance of the proposed algorithms in a multiuser OFDM-JRC system. The main evaluation metrics include bit error rate (BER), peak-to-average power ratio (PAPR) and system spectral efficiency to verify the optimization effect of each algorithm.

(1) Bit Error Rate (BER): simulation results show that the OFDM channel estimation technique using deep learning model effectively reduces the BER, and exhibits higher robustness under multipath fading and noise conditions compared to traditional channel estimation methods.

(2) PAPR suppression: The CNC-IAF method is superior to the conventional method in PAPR suppression, especially in the JRC system, using the Airy function for limiting high amplitude signals, the CNC-IAF reduces the PAPR while retaining a lower BER, which ensures the transmission quality of the system.

(3) Transmission stability: In multiuser MIMO-OFDM systems, the APGM algorithm significantly improves the transmission stability of the system.APGM is able to ensure the control of inter-user interference based on multiple iterations of optimization while reducing the PAPR and improving the efficiency of the power amplifier's linear usage. Compared with other algorithms, APGM has higher convergence speed and lower computational complexity.

7. Conclusion

In this paper, an OFDM-based radar communication integrated system is proposed to solve the PAPR, channel fading and fuzzy lifting problems in the system by applying CNC-IAF limiting method, deep learning channel estimation and OFDM-LFM. Simulation results show that the optimally designed OFDM-JRC system has significant advantages in enhancing spectral efficiency, reducing PAPR, and improving channel estimation accuracy.

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