Design of Integrated Communication System under UAV Network

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Abstract: Integrating sensing function into communication equipment to realize sensing integration function is becoming a key feature of UAV communication network. Existing sensory-pass fusion schemes focus on a single waveform, under a single frequency band design, and lack a discussion on the complexity adaptation of the scene and the algorithm. At present, UAV perception mode focuses on radar active detection and perception, and there is a delay problem in the sharing of perception information. In this paper, a kind of waveform library is first proposed to realize the best cost-effective communication scheme in different flying scenarios.

Key words: UAV communication; sensory fusion; waveform library; waveform decision; multi-perception fusion;

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Design of Integrated Sensing and Communication System Based on UAV Network

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Abstract: It is becoming a key feature of UAV communication network to integrate sensing function into communication equipment to realize sensing communication integration. The existing perceptual communication fusion schemes focus on the design under a single waveform and single frequency band, and lack of discussion on the adaptation of scene and algorithm complexity. The current perception mode of UAV focuses on radar active detection and perception, and there is a problem of time delay in perception information sharing. For this reason, this paper first proposes a waveform library idea based on perceptual information drive to achieve the best cost performance ratio of the communication scheme adopted by UAVs in different flight scenarios. Based on the hybrid waveform concept, this paper proposes a design scheme of active passive fusion synchronous sensing, and matches with an adaptive sensing algorithm based on compressed sensing. Through simulation, it is proved that the overhead caused by sharing perceptual information among UAVs can be reduced, and improve the passive side sensing accuracy.

Keywords: UAV communication; Sensation fusion; Waveform library; Waveform decision; Multi sense fusion;

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0 Introduction

In recent years, the demand for intelligent UAV with both communication support and sensing and detection functions has shown a rapid growth trend, and the integrated communication and sensing technology based on UAV is the best option to solve this problem. Different from the existing fusion system used in vehicle network-end, the UAV platform faces some challenges due to the limitation of more complex mobile trajectory, more variable channel status and lower endurance. In addition, the existing UAV spectrum resources are increasingly scarce, so it is urgent to develop multi-functional equipment that share spectrum. UAV millimeter-borne radar and 6G-based UAV communication will occupy greater bandwidth resources, resulting in the overlap of frequency bands used by the two technologies, which objectively promotes the integration of UAV perception and communication functions. At the same time, at the hardware implementation level, wireless communication is becoming more and more similar to the perceived system transmitters, receivers and signal processors. Based on the above three reasons, intelligent perception and communication integrated equipment used in UAV field has great significance, drones by learned UAV flight state parameters, at the same time in high mobile quality communication and accurate environment state detection, so the research based on the parameter estimation of integrated waveform is of great practical significance.

1. Research status, both at home and abroad

The current UAV platform waveforms include perception-based integrated waveforms and communication-based integrated waveforms. Sense-based integrated waveforms include modulation communication data to FMCW waveform [1], LFM series waveform [2], and waveform [3] based on Chrip signals; communication-based integrated waveforms include OFDM-based waveform [4], and OTFS-based waveform [5]. For OFDM waveform, Yongjun Liu et al. introduced MIMO-OFDM into the radar integrated communication system [6] to improve communication capacity and maximum fuzzy distance; Qing Zhou proposed adaptive sparse matching tracking method based on compression sensing to improve target detection accuracy [7], due to severe subcarrier interference caused by Doppler bias under high mobility, OFDM based integrated system is not suitable for high-speed UAV scenarios.

Now the new waveforms, including OTFS, are the new options in high-mobility scenarios. The orthogonal time-frequency space (OTFS) modulation proposed in [8] has been shown to have significant performance improvements over OFDM in dual-dispersive channels. Most importantly, the OTFS modulation allows a direct interaction between the transmitted signal and the DD domain channel properties, such as the delay and Doppler shift, which is perfectly consistent with the purpose of sensing. To this end, the single-antenna OTFS-ISAC system implemented in [9] implements the perception and communication maximum likelihood (ML) estimator and the multi-input and multi-output (MIMO) -based radar sensing system developed in [10] both demonstrate the effectiveness of OTFS signaling in communication and sensing.

Another important factor affecting the sensing communication convergence is the spectrum resources. With the increasing frequency and bandwidth of the communication center, the communication spectrum is getting closer and closer and even coincides with the radar spectrum. In the early stage, the simultaneous realization of perception and communication functions under the same equipment adopted the strategy of the separation of two devices to achieve spectrum separation, but it will produce many problems, such as increased system volume, energy

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consumption and weight, complex operation, increased redundancy, increased electromagnetic interference between devices, and decreased system performance. At present, the integrated radar communication system based on RS-OFDM realizes [11] through common band time division multiplexing, and the same system of Internet of Vehicles ISAC system based on OTFS also adopts the way of common band time division multiplexing [12]. Currently collaborative wireless communication for multi-frequency band collaboration between Sub-6 GHz and millimeter wave frequency band, such as out-of-band information assisted millimeter wave channel estimation environment sensing [13] control face user surface separation architecture control signaling low frequency transmission and useful data high frequency transmission [14], and the corresponding high and low frequency wireless collaboration network [15], and the main idea of high and low frequency collaboration is to use the electromagnetic radiation characteristics of different frequency bands, signaling, communication, perception and other different functions.

1 Scene description

The application scenario of multi-antenna uav sensing and communication integrated system is shown in Figure 1, where UAV is divided into fixed wing and rotor UAV according to amics. UAV is equipped with multi-functional antenna array, and sensing and communication share a set of transmitting receiver devices. The uav senses the complex scene targets and other uav perception, and updates the scene information in real time in the form of information sharing within the uav network, so as to realize the tasks such as target tracking, collision avoidance and the uav network topology planning. At the same time, UAV has the function of providing communication for users and other UAVs. This paper focuses on the perceptual communication between UAVs.

Fig.1 UAV Integrated Sensing and Communication (ISAC) System

As shown in Figure 1, the UAV sensing and communication integrated system studied here is based on the communication equipment, so that it has the function of both scene sensing and data transmission. What each UAV receiving antenna receives is the target echo and other UAV sensing integrated signals. The transmitting antenna array can radiate sub6G signal and millimeter-wave signal, realizing wide-area coverage and high-precision sensing communication in small areas.

3 Design of sensory fusion scheme based on waveform library

3.1 Scheme description and scene analysis

The core concept of the sensing-pass fusion implementation solution based on the waveform library is that the system can adaptively adjust the emission waveform driven by the perceptual information, so as to meet the needs of the communication QoS and reduce the load pressure of the UAV. Common waveform schemes can be divided into multi-carrier systems and single-carrier systems. The most widely discussed waveforms include the OFDM family waveform, the generalized frequency division multiplexing waveform (GFDM), the elliptical spherical wave multi-carrier index modulation (PSWFs), the OTFS waveform, and the single-carrier SC-FDMA waveforms. The different waveform features are shown in Table
1. Here, we focus on the more sensitive parameters in the UAV scenario, including the resistance to multi-path interference, Doppler bias, system implementation complexity, and peak average power ratio.

Table 1 Electromagnetic characteristics of common communication waveforms

| Waveform | Anti-m | Anti-Doppler | Complexity | PAPR | The Carrier |
|----------|--------|--------------|------------|------|-------------|
| OFDM     | yes    | deny         | lower      | tall | Multi-carrier |
| GFDM     | yes    | deny         | lower      | low  | Multi-carrier |
| PSWFs    | yes    | deny         | higher     | tall | Multi-carrier |
| OTFS     | yes    | yes          | tall       | tall | Multi-carrier |
| SC-FDMA  | deny   | deny         | low        | low  | Single carrier |

Moreover, these waveforms have some unique characteristics, such as the energy concentration of elliptical waves; GFDM solves the problem of excessive PAPR caused by excessive OFDM out-of-band radiation, enabling higher communication capacity at the cost of reduced BER performance; SC-FDE system solves Doppler bias with its single-carrier characteristics, but its data throughput is limited.

Here, we apply OTFS, OFDM-FDE and SC-FDE to build a waveform library for the integrated scenario of UAV waveform communication. The waveform library proposed in this scheme can replace or add more waveform schemes according to the actual requirements. This section discusses the transmitter receiver structure and the fit frame structure.

Different from the existing integrated design scheme using a single waveform, this paper considers the different operational complexity of different waveform transmitters in the modulation process, which will produce different delay overhead and energy overhead. Because different waveforms have different performance differences in different scenarios, this paper uses the waveform library to mine the potential signal processing complexity and QoS performance compromise scheme. The perceptual information-driven waveform library design is shown in Figure 2.

In addition, for OTFS and OFDM system applied in this scheme case, there is a hardware compatibility [16], that is, OTFS system can take OFDM system as the carrier. In addition, OTFS system can be regarded as the linear coupling [17] of OFDM and SC-FDMA system, which provides a theoretical basis for the compatibility of three waveforms under unified hardware equipment.

At the same time, for the three waveforms, their performance is close at low speed and few scatters; and in high moving and multi-scatters, OTFS fights serious Doppler bias and frequency expansion significantly better than OFDM system [18], but OTFS system increases symplectic Fourier transform pair compared to OFDM, the signal processing complexity increases significantly [19] relative to OFDM, leading to higher terminal processing delay. At the same time, OTFS performs better than OFDM in the channel coding short code low overhead scenario, while when the channel coding cost is large, the performance difference is not obvious [20]. However, the SC-FDMA system based on its single-carrier characteristics, the ability to resist frequency bias and phase
noise is strong compared with OFDM, but also reduces the data transmission rate.

Therefore, if a single waveform is used indiscriminately for the UAV platform, it is not conducive to the comprehensive implementation. Table 2 shows the OTFS system complexity based on OFDM and the OFDM system complexity.

**Tab.1 Computing Complexity of OTFS, OFDM and SC-FDMA Systems**

| Waveform | Modulation complexity | Demodulation complexity |
|----------|-----------------------|-------------------------|
| OTFS     | $MN \log_2 M$         | $MN \log_2 M$           |
| SC-FDMA  | $N \log_2 N$          | $N \log_2 N$            |

In addition, OTFS has advantages in perception accuracy performance compared with OFDM. Raviteja points out that OTFS-based radar waveform has higher accuracy than OFDM-based radar waveform in terms of speed detection, and OTFS has higher detection resolution than OFDM in high mobile scenarios, which is beneficial to improve the perception-assisted communication performance under the sensing fusion system in high mobile scenarios.

To comprehensively quantify the "benefit" and "cost" reflecting the choice of different waveforms, here we define the "cost performance" parameter $C$. The parameter is inversely proportional to the algorithm error rate $E$, inversely proportional to the energy consumption parameter $P$, and perception accuracy $S$ (measure using the normalized range profile parameter reciprocal Normalized Range Profile, NRP), but also refer to the 4G-LTE capacity demand waveform adaptive strategy, according to the capacity requirements under different scenarios of single carrier and multi-carrier waveform application scenarios.

The energy consumption parameter $P$ here is the "power" required by the algorithm, which is directly proportional to the number of complex operation units required for the same hardware system $M$. And it is obviously noted that the value is determined under a fixed communication block size condition: Throughput-Capacity demand ratio Demand satisfaction requirements Capacity ladder function $F$:

$$F = \begin{cases} 10 & \text{高容量需求多载波或低容量需求单载波} \\ 1 & \text{低容量需求多载波或高容量需求单载波} \end{cases}$$

Moreover, it makes no sense to directly discuss the cost performance of an individual moment $t$, because the overall performance and overhead that we focus on is often the statistical average of the probability over time. Therefore, the "cost performance" parameter expression of the $T-1$ transceiver is as follows:

$$C = \sum_{i=0}^{N-1} \sum_{j=0}^{T-1} F \log \left( \frac{S}{E \cdot C_M} \right) p_i(t)$$

For a pair of transceiver drones, the corresponding overall "cost performance" is expressed as: Here, the waveform used by the transceiver is consistent. $C = \frac{C_T + C_R}{2}$

$p_i(t)$ It indicates the probability of selecting the waveform with number $i$ within time $t$. Since the collected perception information will identify the current UAV flight scene and make the waveform adjustment in real time, the probability is related to the actual flight scene of the perception information detection and recognition. For example, one of the most representative flight modes can be described as: the drone takes off from an unmanned airport and enters a service area after a certain period of rapid flight. According to the different service objects and service needs, the flight process of the service area is evenly divided into high-speed...
multi-obstacle flight area, low-speed multi-obstacle area and other areas. The UAV adjusts the waveform parameters in real time to improve the communication cost performance level.

3.2 Design of transmission protocol for adaptive fusion waveforms

Based on the perception-driven fusion waveform transmission system, we propose an adaptation protocol model with the following design for the perceptual frame control frame slot.

Data frame consists of two frames: data frame (Data Frame) functional frame (Control Frame) and implanted with pilot at the necessary position. The uplink control frame includes three seed frames: data transmission control, information sensing, and waveform control. The uplink data frame structure is shown as follows:

![Fig.4 Uplink data frame structure](image)

The perceived data frame has Echo characteristics. When the "active perception mode" is selected, it transmits the perceptual data in Echo mode to obtain detailed perception information. The waveform control frame instructs the receiver UAV to adjust the waveform. The waveform control frame is very important for the fusion waveform system, so we use in-frame coding to expand the original one-bit information to 8 bits. In this paper, it is suggested to make an adaptive adjustment of the channel state information according to the perceptual information. The specific method is not discussed too much.

The transmitter extracts the required sensing information according to the acquired sensing data frame, including the relative movement speed, the communication distance, the multiple channel path number generated by the scatterer, and the beam angle other information for the multi-antenna system. The first three of the information will determine the kind of waveform that we adopt, and here the decision mode will be discussed together with the decision mode of the post-sequence spectrum library.

For the downstream data frame, it includes the receiver data and the control response information, and when the "response perception mode" of the multi-perception collaboration is selected, the downstream data frame will also contain the perception data frame. The downlink data frame structure is shown as follows:

![Fig.5 Downlink data frame structure](image)

The Wave Mode Response data frame characterized whether the receiving UAV was used in response to the waveform adjustment. It should be noted here that the receiver UAV will not adjust immediately after sending the waveform adjustment instruction. When the command is transmitted at the same time, the waveform adjustment will be made after ensuring that the data is fully transmitted.

For the protocol application of dynamic scenarios shown in Figure 6, the sensory pass fusion system will adaptively adjust the distribution density of perceptual data frame and information data frame and data frame waveform format, as shown in the following figure, after completing the perceptual data extraction and analysis work, the UAV adjusted the data frame mode. In the scenario of fewer low-moving scatterers with good communication conditions, Less perceived data frames, At this time, the perceived information has a good "time persistence". Meanwhile, the waveform library controller is adjusted to be a waveform...
option suitable for long endurance performance. And change the transmitter and receiver waveform through the control protocol; When the drone moves faster, or after the sensing controller has detected a relatively higher mobile signal receiver, At this time, the waveform library filters the waveform suitable for high mobile scenarios according to the following algorithm, jointly adjust the transmitter receiver waveform through the control protocol, It will also improve the density distribution of the perceived data frames, To achieve real-time awareness of information synchronous update.

3.3 Waveform library decision algorithm design based on reinforcement learning

According to the aforementioned both spectrum library and waveform library decision purpose, there are actions based on the environment, in order to maximize the expected revenue characteristics, where the library scheme is finally expected to achieve the best cost performance for a certain period of time can be considered as a reward function, so the decision of the library scheme can use the reinforcement learning method.

In addition, because the reward function involved parameters is not much, so the decision mechanism can also use "table method" design implementation, but the method requires prior simulation or actual acquisition parameters, and binding with the actual flight scene, poor performance for changeable scenarios, lack of robustness, this paper summarizes the following table 3 for “table method” case.

Multi-band collaboration based on deep reinforcement learning aims to gradually optimize the multi-band multi-waveform aware communication collaboration strategy for the UAV common sensing integration system through the offline/online trained deep reinforcement learning model. In this example, the low-frequency RF sensing system periodically performs coarse-grained sensing, while the high-frequency band common transduction integration system conducts fine-grained sensing according to the sudden communication request, and updates the model online according to the actual flight scenario, with good robustness characteristics.

Therefore, the multi-frequency band collaboration method in this example can be designed to decide the reinforcement learning model on the start-end moment, bandwidth for low- or high-frequency radio frequency sensing under the number of obstacles, TRS, and library-based communication performance optimization induced by obstacle-user trajectory prediction or beam alignment tracking. Here we present the following analytical discussion on the decision problem adopted under the Q-Learning scheme.

| Tab.1 Electromagnetic Characteristics of Common Communication Waveform |
|---|---|---|---|---|---|---|---|
| Communication Data frame translation haul Channel Waveform | matrix | I speed | up | multi-diameter | mode | requirement | dimension |
| High data | 32*32 | <10m/s | <100 | <30 | OFDM | m | n |
| volume | m | n |

Q-The agent, state, action space, and reward functions in the Learning are as
follows:

(1) Agent: UAV monomer $i$;

(2) Status: For each moment $t$, the perceived information status currently acquired by the UAV $i$, including the channel multiple path number, the relative movement speed, and the communication distance of each communication path; and the communication built-in parameters, including the current communication frame block mode, are expressed as a state matrix. $N_L, \Delta v, \Delta L, Mod_{size}$.

$State = [N_L, \Delta v, \Delta L, Mod_{size}]^T_i$

(3) $Mod_M Mod_F$. The action space is different in waveform mode or frequency band mode according to the current target. For example, the waveform mode has OTFS and OFDM waveforms, whose corresponding labels are 0 and 1. For each time $t$, the action of UAV $i$ is expressed as: $action = [0,1]^T_{i,d}$.

(4) The immediate reward function represents the reward for performing an action in the state of the $t$-th time slot. The algorithm sets the initial state, and determines the transmission action of the next round according to the input state matrix discrimination information. At this time, the weight parameter is updated according to the gradient descent method according to the current estimated value and the target value.

(5) In addition, in order to realize rapid decision making and improve the efficiency of reinforcement learning algorithms, a table storing prior information is added here, combining the Q-Learning algorithm to realize a hybrid decision scheme of “table-up-Q-Learning”.

3.4 Multi-aware collaborative scheme based on library scheme decision

3.4.1 Multi-aware collaborative protocol design

Based on the fusion waveform collaboration scheme, the perception mode can be further divided according to the different subjects and objects of the perception side. This paper starts from the time division reuse, and the perception mode is divided into the active perception based on the traditional radar mode and the active and passive fusion perception proposed in this paper. The schematic of the two percepmeths are as follows:

Figure 7. Schematic diagram of the two perceptual modes

Fig.7 Schematic diagram of two perception modes

In the UAV network scenario, in order to realize the demand of perceptual information sharing in the UAV network, there will be a part of the data frame in the transmission data frame in the traditional radar communication integration scenario. The advantage of the active and passive sensing fusion scheme based on OTFS communication waveform over the radar mode is that the transmitter receiver can complete the sensing task while communication, thus reducing the overhead for sharing sensing information. The time division protocol comparison diagram of the two schemes is shown below.

Fig.8 Data frame structure of two sensing modes

$U_i$ Among them, the main role of the active perception object is the perception signal sender of the perception signal, which is not mandatory for the adopted waveforms. The core of the algorithm is to use the radar echo to
estimate the related parameters of perception, while the estimation algorithm will be different according to the different waveforms. All the waveforms can extract the perception information by matching filters. The actively aware uplink data stream contains two data frames, aware frames and communication frames, while the downlink data stream only has communication frames by default. The UAV that needs to obtain the perceptual information first sends the perceptual data frame, which adopts a data content distribution structure different from the communication data frame, so that it can be used to distinguish the general data echoes after the echo reception, so as to facilitate the detection and extraction. At the same time, due to the three-dimensional spatial characteristics of uav communication, the sensing data frame transmission needs to meet the Angle scanning rules, that is, the difference from the Internet of vehicles lies in that here we add the spatial Angle domain sweep, that is, to increase the $\pm \Phi^*$ sweep of the vertical Angle domain. The data flow arrives, and the isosscatterer forms a reflection echo, when the reflection echo is received and the frequency bias, delay and angle are calculated. In the process of normal communication, the UAV can still receive reflected electromagnetic waves and realize the effect of sensory fusion. However, because the transmission data frame structure is different and not easy to meet the optimal statistical distribution, the extracted perceptual information extracted is not as accurate as the perceptual information frame. $U_2 O_1 O_2 U_1 U_3 U_4 U_5$

The passive sensing subject in the active and passive fusion perception is the receiving UAV. After receiving the transmitting UAV signal, the spatial position information of the sending UAV is transmitted according to the feature analysis and processing of the receiving signal channel. The following subsection describes the details of the algorithm in active and passive fusion perception.

3.4.2 Active and passive perception fusion design based on OTFS communication waveform

The OTFS algorithm in the waveform library scheme makes it possible to realize both active perception and passive perception in the same UAV sensing fusion system. Because the OTFS algorithm directly defines the delay-Doppler domain of the sensing information, the receiver can directly convert the OTFS reception signal into the DD domain channel matrix, while the DD domain channel matrix can be directly converted to the absolute motion speed size, relative motion speed size between two drones, distance between drones and relative orientation angle according to the algorithm. In addition, the OTFS waveform can be inserted by designing the DD domain structure, which can be inserted in the communication data, and map to the frequency domain to form an efficient spectral utilization in the form of FDM. Specifically, the UAV adopts the detection OTFS waveform sensing data frame, which is sent to form the echo at the same time. At this time, the sensing data frame forms the side measurement sensing information, while the echo forms the sensing information there. Due to the different reflection coefficient of the scatterer, the two sensing information will be slightly different. There is a potential space for optimization for this difference, but the difference is often not very obvious. However, with the coexistence of the two perceptual modes, the time overhead of the perceptual information interaction can obviously be reduced and save the channel time resources. $U_1 U_2 U_3 U_4 U_5 U_6$

It can be noted that the response perception is not suitable for the communication relationship establishment
stage, because the subject is the receiver, but it is very suitable for the communication process. Therefore, we suggest to adopt the detection and sensing algorithm in the synchronization stage, and make the use of the response sensing algorithm to realize the fusion of sensing tracking and sensing communication after basically establishing the UAV electronic map. Suitable for active and passive collaborative sensing scheme implementation. Both active sensing and passive sensing use the communication channel estimation algorithm to realize perceptual data acquisition.

\( U_1 x h U_2 y \) For the signal transmitter UAV transmits a piece of data, it passes the multi-path channel and then receives it by the receiving UAV. At the same time, the signal returns to the transmitter and the UAV receives the reflected echo. \( U_1 r \)

\( U_2 y \hat{h}_1 \) At this time, the delay-Doppler channel matrix is estimated for the received signal according to the pilot frequency, and the relative distance and the movement speed corresponding to each obstacle i can be directly obtained according to the parameters such as the carrier frequency specified in the previous protocol, and the information is stored to the local storage. \( \hat{I}_1 \hat{v}_1 U_2 \)

\( U_1 r x h_2 x 2 \hat{h}_2 \hat{v}_2 l U_1 U_2 \) At the same time, for according to the echo and the equivalent of the current transmission information has experienced the channel (which can be considered experienced each diameter delay and the influence of Doppler bias), and can directly take the emitted data block as a pilot channel estimation, can eventually obtain the corresponding relative distance and moving speed information of each obstacle. In this way, the perceptual information is obtained independently, avoiding the overhead of perceptual information exchange between drones.

For the high-accuracy sensing combined with OTFS waveforms, this paper recommends a sensing scheme based on the orthogonal matching tracking algorithm, which can achieve higher performance sensing accuracy compared to the matching filter while realizing the sensing task under communication conditions. A parametric adaptive strategy for MF algorithm is also proposed to form a "semi-blind" form of perceptual estimation. Subsequent simulations show that our proposed algorithm can simultaneously improve perception accuracy and sensory fusion efficiency. The algorithm can be divided into two steps matching trace kernel loop with sparsity adaptive outer loop. One of the perception estimation algorithms based on OTFS-GOMP is as follows:

**Algorithm 1**: OTFS-GOMP Algorithm

```plaintext
Require: 采样数据及感知阵 X:
接收信号矩阵 \( r \)
单载波信号子数 L:
送信信号子数 R:
output 估计参数矩阵 \( \hat{h} \):
\( h_0 \leftarrow r \)
\( A_0 \leftarrow \theta \)
根据 MF 算法估计感知参数矩阵延迟度
\( M_{\text{est}} \leftarrow \arg \min _{\hat{h}_0} \left| y - (A_0 \hat{h}_0)^\top x \right| \quad \text{if} \quad (y_0 - y) \left| y - (A_0 \hat{h}_0)^\top x \right| < \varepsilon 
\text{end for}

Based on the more accurate perceptual parameter estimation information, and combined with the existing mature messaging detection algorithm [21] (Message Passing, MP), a more efficient and accurate data recovery function can be realized.
4. Simulation analysis and feasibility verification

A. Feasibility verification of the waveform library scheme

A simple simulation analysis of the waveform-based library is presented. Our simulation analysis of the single waveform system and "waveform library" scheme "cost performance" parameters in dynamic scenarios, in order to verify the waveform library scheme can realize the system performance (BER), algorithm complexity and communication capacity parameters better cost performance. The simulation scenario is divided into five stages here:

Stage A: The UAV takes off, where the movement speed is low, the obstacles are less, and the communication content is mainly to control the signaling;

Stage B: Then the high speed passes through a relay communication area of a control station, where the communication demand is small, and there are fewer obstacles, but the relative movement speed is very high;

Stage C: Then the high-speed passes through a section of image acquisition and multi-UAV communication area, which meets the high movement speed and many obstacles, and has a high communication quality and capacity requirements;

Stage D: After completing the task, enter the communication UE intensive area, where the UAV reduces the speed or even hover to provide temporary base station services, and the area provides large-scale communication services;

Stage E: Finally, all the tasks are completed, and the drone returns to the airport. The "performance-energy consumption-capacity" cost performance simulation evaluation results of each single waveform system and the "waveform library" scheme are shown as follows. According to the results, the waveform library scheme (ideal judgment), compared with other single waveform schemes, can approximate the optimal solution to ensure the best cost performance in each time period.

Fig.9 Comparison of single and waveform library "cost performance" simulation at different stages

B. Feasibility verification of the waveform library decision algorithm based on Q-Learning

We use the Q-Learning algorithm to simply simulate the feasibility of the waveform library decision method in a uniformly accelerated dynamic scenario. The cost represents the "reward", which reflects the current performance of the waveform library, and the simulation compares the robustness of the ideal decision scheme (that is, the best waveform scheme at all times), the hybrid decision scheme based on the "table checking-Q-Learning", and the simple table checking method. According to the results, the recommended hybrid decision scheme based on "table checking-Q-Learning" can realize the effect closer to the ideal decision. Comparing the single table checking method, due to the online learning process, this method improves the overall robustness, especially reflected in the communication channel state changes dramatically, can still maintain the high decision cost performance.
C. Feasibility verification of multi-antenna active-passive fusion sensing scheme based on compression sensing

According to the previous algorithm, this section compares the MF sensing mode in the MIMO-OTFS millimeter wave channel scenario under 2T 2R antenna, the SAMP and the recommended adaptive GOMP based scheme for data detection. The simulation results show that our recommended compression sensing scheme has more obvious advantages in detection accuracy, and significantly improves the performance of the algorithm that relies on sensing information for symbol detection. Here the perceptual accuracy is measured using the normalized mean square error NMSE:

$$\text{NMSE} = \log \left( \frac{\sum \left| s(n) - \hat{s}(n) \right|^2}{\sum |s(n)|^2} \right)$$

D. Validation of perceptual overhead performance based on active and passive fusion perception scheme

Here we are based on a UAV network composed of five UAVs, and the simulation analysis verifies that active and passive sensing can reduce the average overhead per UAV for sensing function. And assume perception data frame corresponding to physical frame length of 1, sharing the cost of perception data considering communication obstacles is so much that every two drones need to share perception information exchange, and assume each sharing exchange overhead is 2, and assume every three time interval for perception detection operation, single perception and active and passive fusion perception accumulated overhead simulation
comparison is as follows:

![Fig.12 Cost comparison of different perception schemes](image)

Fig.12 Cost comparison of different perception schemes

![Fig.6 Rendering of waveform library scheme in dynamic scene of data frame structure of two perception modes](image)

Fig.6 Rendering of waveform library scheme in dynamic scene of data frame structure of two perception modes

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