

Research and Implementation of High-speed Aeronautical Communication Technique Based on OFDM

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Abstract—This paper presents a novel High-speed aeronautical communication technique based on orthogonal frequency division multiplexing (OFDM) and practical implementation of it. We described several blocks in the OFDM system to establish the specifications for the receiver which is in the airplane equipment. Especially, the synchronization block and channel estimation block play a key role among the receiving blocks in the aeronautical communication receiver, and for this we describe it in detail here. We also include descriptions of several implementation techniques in receiver. We then implemented the system using the selected algorithms in a physical simulation environment. Simulation and the implementation results proved that this proposed technique is effective for mobile subscriber and can be employed efficiently in aeronautical communication.

Keywords—OFDM; High-speed aeronautical communication; timing synchronization; frequency deviation correction

I. INTRODUCTION

With the increasing demand of communication technology in aeronautical area, besides robust transmission quality, low latency, flexible networking, and anti-interference ability, the most obvious difference compared with current aeronautical communication systems is the significant improvement of transmitting data rate. How to effectively utilize the limited frequency resource and transmit High-speed digital information reliably in the aeronautical wireless channel, is the facing problem in the aeronautical communication research. Multi-carrier OFDM technique, with the advantages of resisting frequency selective fading, high frequency efficiency, convenience to be combined with other techniques, is the candidate technique in the future aeronautical communication. However, considering the features of aeronautical wireless channel and the special requirements of application, there are several key problems awaiting solution in design of future aeronautical communication system based on OFDM.

Compared with widely studied terrestrial communication channel, there is much larger Doppler shift in aeronautical

channel [1], the signal is enduring much more attenuation, and the channel model varies with the aircraft's relative position. The channel estimation algorithms in aeronautical time-frequency double-selective channel and the low-latency anti-fading method are the difficult and important problems in future aeronautical communication research.

OFDM has gained a high popularity in the last few years and is currently regarded as the leading candidate for beyond 3G mobile communication systems, and has been adopted in many new-generation wideband data communication systems, such as DAB, DVB and High-speed wireless LAN [2]. The basic principle of OFDM is to sub-divide the information bit stream into a large number of bit streams, each with low individual bit rates, which are then carried on individual orthogonal sub-carriers [3]. This transmission technique is especially suited for mitigating the effect of the multipath fading channel that usually occurs during mobile reception [4].

The OFDM technique is effective in coping with many channel problems, such as intersymbol interference (ISI), multi-path and pulse noise, which is especially severe in high data rate transmission of frequency-selective channels. This paper describes the design of the many blocks that are important for aeronautical communication system, with special emphasis on the synchronization blocks. The overall performance of OFDM systems is very sensitive to time and frequency synchronization offsets. We modeled and simulated the High-speed aeronautical communication using Matlab with different channel environment models. DSP and FPGA implementation was described in succession. finally, we verified the reliability of High-speed data transmission in practical implementation system.

The rest of the paper is organized as follows. Section II presents a brief review of the High-speed aeronautical communication system, focusing on the synchronization and channel estimation algorithms of the receiver. Sections III describe the implementation of the OFDM receiver respectively and a performance evaluation of the system. Lastly, section IV contains our conclusions.

II. SYSTEM MODEL

A. Brief Description of the High-speed aeronautical communication system

Fig. 1 shows the system block diagram. The transmitter part of the High-speed aeronautical communication system includes data main control block, baseband process block, up-converter block. The receiver part includes down-converter block, synchronization block, baseband process block, data main control block. Considering the symmetries between the transmitter and the receiver, and the receiver is more complex, so only the OFDM receiver is described here.

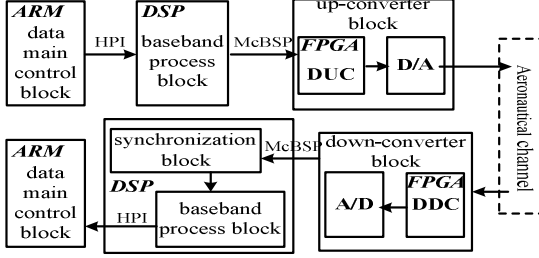


Figure 1. block diagram of High-speed aeronautical communication system

The hardware resource of receiver part may be divided into many sections: the blocks inside the rectangle labeled “FPGA” are implemented in a Xilinx XC4VSX55 FPGA chip, which contains intermediate frequency (IF) signal Digital Down Conversion (DDC) processing. The blocks inside the rectangle labeled “DSP” are implemented in a TI 320C6701 DSP chip, which contains the base-band (Fig. 2) signal processing: synchronization, FFT, deinterleaving, 16QAM demodulation and Turbo decoding. The data transmission is controlled by ARM, the practical implementation environment is used to verify the quality of system.

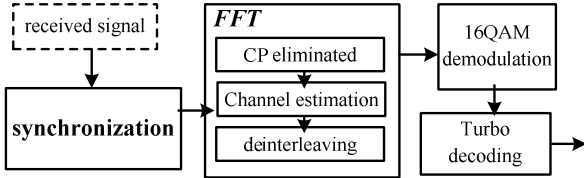


Figure 2. block diagram of baseband process block

The received signal is transmitted to the receiver via the wireless channel, which is assumed to be a multipath Rayleigh fading channel [5]. At the OFDM receiver, the received signal is first down-converted to the baseband, filtered and sampled, and processed by the synchronization block. The signal is generated by frames and symbols, so the received signal has to process the signal frame by frame. Thus it's important to locate the position of each OFDM frame. In the synchronization block, the frequency and timing offset are estimated and used to compensate the received signal. So we will describe the synchronization block in a separate subsection especially.

In the FFT demodulation block, the cyclic prefix (CP) is eliminated, and the OFDM symbols are reconstructed. The

deinterleaving block rearranges the symbols in the order of the primary sequence and 16QAM demodulation is then performed.

B. Structure of a transmission frame

The transmission signal is arranged into a transmission frame which consists of three parts as shown in Fig. 3.

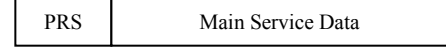


Figure 3. Structure of a transmission frame

The first is the phase reference symbol (PRS). This symbol contains information for the calculation of the frequency and the time deviation and serves as reference for the differential QPSK demodulation. Calculation of the frequency offset is performed with autocorrelation sequences. Also the estimation of the time offset and channel condition can be done in the frequency domain with PRS.

Each transmitted data block in a transmission frame is preceded by a cyclic prefix, and the length of CP is usually equal to or larger than the maximum delay spread of channel to eliminate intersymbol interference (ISI). So the ISI could be ignored usually [4].

C. Synchronization Block

At the receiver, synchronization block is required for the signal demodulation in the system. Without symbol synchronization, the effects of ISI will degrade the system performance in the system. Also, a critical weakness of OFDM is its sensitivity to carrier frequency offset [2] [6]. Offset and correction are the key block of this system. It estimates and corrects the frequency offset due to Doppler shifts and local oscillator drifts.

Frequency offset normalized to the subcarrier spacing can be divided into an integer part and fractional part. The proposed synchronization block has three main sub-blocks: the symbol timing synchronization, fine frequency offset synchronization and integer frequency correction. The blocks are implemented as following:



Figure 4. The sub-blocks of synchronization

1) *Symbol Timing Synchronization Block* : The fine timing synchronization block locates the exact position of each frame. The PRS is in the start position of the transmission frame. If we can find the position of PRS, the corresponding data frame is located. Use the PRS to estimate the timing offset.

Define the cross-correlation function:

$$T_f = \text{MAX}_m \text{IFFT}\{z_{prs} \times r_k^*\} \quad (1)$$

Where

z_{prs} is the PRS at the transmitter (frequency domain); r_k is the received base-band signal (frequency domain); m is the index of samples in the searching region.

There will be a high peak in the image of $IFFT\{z_{prs} \times r_k^*\}$, and the fine frame start can be then determined [7].

2) Fine Frequency Offset Synchronization Block: The fractional part of the frequency offset causes intercarrier interference (ICI) that resembles AWGN at the FFT output and which must be corrected before OFDM reconstruction. Assume that, there is only frequency offset less than half of the sub-carrier spacing after Integer Frequency Synchronization Block [8]. In this paper, the OFDM guard interval is used to estimate the offset. The OFDM symbol contains a cyclic prefix that is a copy of the original symbol and is called a guard interval. If we let the fractional part of the frequency offset be θ , the received signal before the reconstruction of the OFDM symbol is $iq_{-m}e^{-j2\pi\theta m/N}$ [9]. The fractional part of the frequency offset can be estimated as follows:

$$F_f = \frac{1}{2\pi} \arg\left\{ \sum_{m=1}^G iq_{-m}e^{-j2\pi\theta m/N} \times iq_{K-m}^*e^{j2\pi\theta(N-m)/N} \right\} \quad (2)$$

$$= \frac{1}{2\pi} \arg\left\{ \sum_{m=1}^G e^{j2\pi\theta} \right\}$$

Where

F_f is the estimated frequency offset normalized to the subcarrier spacing, and $-1/2 < F_f < 1/2$; G is the length of the cyclic prefix; $iq_{-m}e^{-j2\pi\theta m/N}$ is the received signal of the OFDM cyclic prefix; N is the length of FFT; $\arg\{\}$ is an operator that extracts the phase term inside the braces.

The frequency offset in the received signal must be compensated using the estimated frequency offset.

The fractional part can be done as follows:

$$S_m = iq_m \times e^{-j2\pi f_f m/N} \quad (3)$$

Where

iq is the output of the I/Q demodulation block with frequency offset; S_m is the compensated signal;

3) Integer Frequency Correction Block:

The integer frequency offset can be estimated not only using the cross-correlation between the received PRS and the PRS in a receiver, but also using the OFDM symbol from the main service data in a transmission frame. Integer Frequency deviation leads to the completely fault in the High-speed aeronautical communication receiver. It can seriously decrease the performance of the system.

If the frequency deviation was large-scale, we introduce the method which utilizes the energy ratio between null carriers and valid carriers to calculate the right integer frequency position [10].

$$K_f = \text{MAX}_i \frac{\text{Energy}[V_{i+M}, V_{i+2M}]}{\text{Energy}[V_i, V_{i+M}]} \quad (4)$$

Where

M is the number of the null carriers, V_i is the frequency point of the current carrier. $\text{Energy}[a, b]$ is the energy aggregation from carrier a to carrier b .

After estimation of large-scale frequency deviation, we can estimate the exact integer deviation offset by the cross-correlation:

$$F_i = \text{MAX}_m \left| \sum_{k=0}^{K-1} z_{local,k} r_{k-m}^* \right|^2 \quad (5)$$

where

$z_{local,k}$ is the PRS or the pilot in OFDM symbol; m is the integer frequency offset; r_{k-m} is the received signal which make a cyclic shift in frequency domain;

$\left| \sum_{k=0}^{K-1} z_{prs,k} r_{k-m}^* \right|$ reaches the cross-correlation's peak value

when $z_{prs,k} = r_{k-m}$.

Integer frequency offset causes a cyclic shift of the FFT output. When the frequency offset lies between 0.5 and 1.5, the FFT output is shifted by 1 in either the counterclockwise or clockwise direction [3] [6].

D. Channel Estimation Scheme

The proposed channel estimation scheme is shown in Figure 5, which can be completed in three steps, including the blocks of phase lock loop, channel parameters estimator, and iterative cancellation. We suppose the received signal is ideally synchronized to the LOS path in this scheme. For convenience, all of the derivations are carried out in continuous time domain. As we analyzed in passage [11], the input of this scheme is $y(t)$, an baseband waveform during an OFDM symbol period T . Since the interference of AWGN can be ignored at first, the received waveform which passes through the two-ray channel will turn into:

$$y(t) = y_{LOS}(t) + y_R(t)$$

or

$$y(t) = \sqrt{\frac{K_{Rice}}{K_{Rice}+1}} x(t) + \sqrt{\frac{1}{K_{Rice}+1}} A(t)x(t-\tau_d)e^{j2\pi f_d(t-\tau_d)} \quad (6)$$

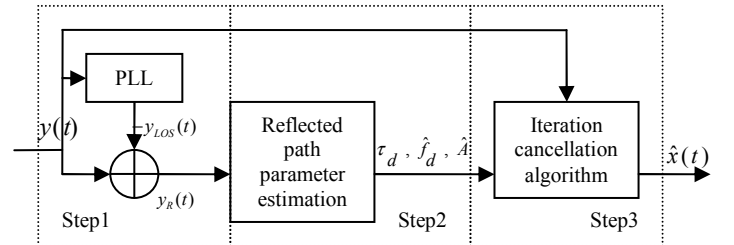


Figure 5. Proposed channel estimation scheme

III. SIMULATION AND IMPLEMENTATION RESULT

The High-speed aeronautical communication technique is implemented based on the algorithms presented in section II. The transmission signal has a central frequency of 2.4GHz, Tuner down-converts the signal to the IF of 24.384MHz.

The performance of the proposed system has been investigated by using the simulation. Firstly, we employ the severe multi-path fading channel model as COST207 TU model [7].

A simulation of 10^6 trails is used to estimate the BER, associated with estimator in different SNR. Consider the data decoding is Turbo coding. System sample frequency is set as 2.048MHz. The length of cycle prefix is set as 32. Presuming FFT point is 256 and Cycle prefix is 64. The modulation mode is set as 16QAM. The number of null carriers is set as 40 and valid carriers is set as 216.

We run the aeronautical communication system by transmitting data by two PC under Linux. At the transmitter, we run data send software generating UDP data at the same time, and sent the UDP data to the transmitter through network. At the receiver, we received the UDP data in the other PC, started data receive software and contrasted the bit error ratio.

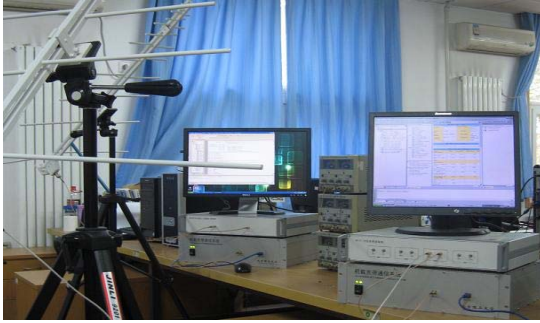


Figure 6. Photograph of the aeronautical communication transmitter and receiver based on OFDM

We obtained the performance of the system. The results demonstrate that the proposed system is robust for High-speed aeronautical communication. Fig. 7 shows the BER of the system under COST207 TU model.

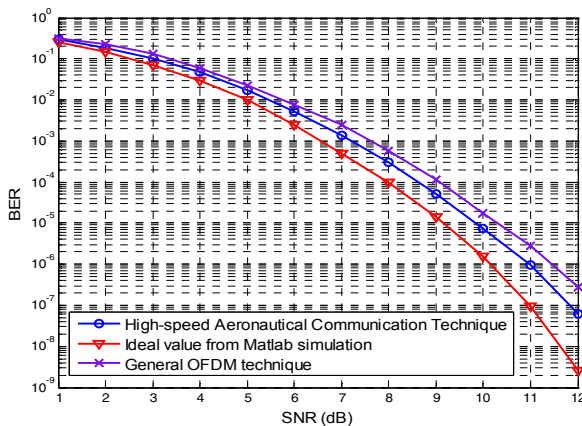


Figure 7. The BER of the system

IV. CONCLUSIONS

The aeronautical communication environment has its own characteristic, which can be utilized to design an optimum method. In this paper, we proposed a novel High-speed aeronautical communication system based on OFDM. It also can be adapted to other multipath sparse transmission channel. The BER performance of the proposed scheme in aeronautical fading channel was carried out by computer simulation and the real test. The Simulation results validate the efficiency of this aeronautical communication system.

The system we implemented uses DSP and FPGA. It makes the system very flexible to applying other better algorithms and adding functionality. We can take their advantages in signal processing. For example, one improvement is to modulate the signal with 64QAM, 128QAM and take more complex channel estimation. Another one is to upgrade the synchronization algorithms being employed. Furthermore, Extension of the proposed synchronization to other scheme is straightforward. We can utilize the adaptive technology to obtain the exact timing and frequency point by using more adjacent OFDM symbols in the bad channel environment and less in the better condition.

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