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Integration of Navigation Radar and Communication Based on QAM-OW Signals

Zhi Li [a,*], Shijun Ying

Merchant Marine College, Shanghai Maritime University, Shanghai, 201306, China

[a]lizhismu@163.com

Abstract: Integrate hardware resources and spectrum to integrate radar and communication by integrating Worldwide Interpe rability for Microwave Access (WIMAX) communication with the new Orthogonal Frequency Division Multiplexing (OFDM) marine radar system. Features. A quadrature amplitude modulation (QAM) WIMAX and radar integrated signal model (QAM-OW model) was established. Then, the capacity of the QAM-OW communication channel is derived accordingly. The radar signal-to-noise ratio is used to evaluate the performance of the radar, and the WIMAX communication channel capacity is used to measure the communication capability. The effect of signal-to-noise ratio on radar performance and WIMAX channel capacity is given by simulation. Theoretical analysis and simulation experiments show that the proposed QAM modulation WIMAX and OFDM system navigation radar integrated signals can effectively realize the WIMAX communication function between ships under the condition of ensuring radar performance.

Keywords: Integration of navigation radar and communication; ambiguity function; Radar Signal Noise Ratio; Bit error rate of integrated signal.

1. Introduction

At present, marine radar mainly uses pulsed magnetron radar, and many shortcomings of pulsed magnetron radar have become less and less suitable for the development of modern navigation technology. The shortcomings and defects of the single-carrier non-coherent pulse and azimuth mechanical scanning system that have been used in traditional navigation radars have gradually emerged. The traditional pulsed magnetron radar has the following drawbacks: there are blind areas, blurred near-range targets, large disturbances caused by weather factors such as rain and snow, magnetrons require warm-up time, and low service life.

The ship's wireless communication system is based on MF, HF, VHF radio for offshore ship-to-shore communications, and satellite communications for long-haul ship-to-ship and ship-to-shore communications. Due to the lack of bandwidth, these maritime radio technologies cannot support electronic navigation services. Using satellites is too expensive for commercial services. In order to solve these problems, an improved maritime communication technology is required to transmit a large amount of multimedia data. Therefore, it is hoped that there is a better communication method, which can quickly transmit large-capacity data, the development of the technology of the active phased array antenna, and the reduction of the cost, making this idea a reality. We hope to install an active phased array radar with large bandwidth communication function on the ship to provide basic communication and navigation support for the development of smart ships.

After decades of technological development, the difference between WIMAX (IEEE802.16j) [1,2] communication systems and active phased array radars is getting smaller[3,4].With the development of processing devices, the processing power and versatility of signal processing devices are also increasing, further reducing the hardware differences between the two systems. Radar systems and communication systems are very important in the operation of ships. The ship obtains navigation information from the radar and can broadcast its own information through the WIMAX communication system. Moreover, the frequency used by the S-band and the current frequency of the WIMAX communication system partially overlap, and enter the receiving device channel or system through direct coupling or compact coupling, resulting in performance degradation, quality deterioration, information error or loss, and even blocking the communication.[5,6]Through the combination of WIMAX signals and radar, WIMAX communication is used to establish a large bandwidth connection between ships. The radar can maintain the perception of the surrounding navigation environment with a small transmission power, effectively reducing interference to the communication system [4, 5]. In addition, sea clutter is an important factor affecting the performance of radar detection. The traditional radar measures the distance and azimuth by receiving the radar pulse signal reflected by the target. It is susceptible to sea clutter. The WIMAX marine radar system can effectively avoid the influence of sea clutter on ship information perception by establishing WIMAX communication connection.

2. Comparison of methods of radar communication integration

The existing radar communication integrated design schemes are mainly divided into two categories: one is an integrated waveform design scheme using multiplexing technology, and the other is an integrated waveform design scheme using frequency sharing technology. The integrated waveform design scheme using multiplexing technology mainly includes frequency division multiplexing, code division multiplexing, time division multiplexing and space division multiplexing. However, this type of technology does not realize the sharing of radar and communication functions on frequency resources, and does not reduce the use of spectrum resources. And the waveform needs to be separated at the receiving end, and the separation quality will have an impact on the recovery of the radar and communication information.

At present, the realization of radar communication integrated waveform signals is divided into two ways. One is to directly use the communication signal as an integrated signal, and the signal itself can complete the communication, and the radar performance can be satisfied by detecting the target. Second, on the basis of the existing radar waveform, the communication information is modulated on its parameters or the waveform itself, and the radar and communication functions are realized at the same time. In the first method, the OFDM signal is widely used due to its high frequency band utilization and flexible subcarrier design. Literature [7-11] studied the OFDM radar communication integration scheme, but the OFDM system radar communication integrated signal scheme has the problem of high peak-to-average ratio. In [12], a phase-modulated constant-envelope OFDM signal is proposed to solve the problem of peak-to-average ratio. However, the modulation factor must be added to make the modulation phase within the working range of the phase demodulator, but the addition of this coefficient will make the pulse. The compressed side lobes rise sharply, causing a drop in resolution.

In the second method, the literature [13-15] uses the linear frequency modulation (LFM) signal as the carrier to modulate the minimum frequency shift keying (MSK) symbol phase, but as the number of symbols increases, the spectrum leakage is severe. Literature [16-17] uses the correspondence between LFM and Fourier transform (FRFT) to achieve communication modulation by modulating the initial frequency and modulation frequency, but with the increase of symbols, the design is complicated. Each pulse pulse sidelobe structure is different, resulting in a distance sidelobe modulation, which leads to a decrease in the coherent accumulation gain and affects the detection performance of the target. Reference [18] uses matrix point division to eliminate RSM, but this method requires accurate delay information of the target. In [19], the power ratio of the main subcarrier is designed to suppress the RSM to a certain extent, but this method cannot realize the energy sharing of radar and communication. Literature [20-21] eliminates RSM by designing filters, but as the number of modulation code sources increases, filter performance drops rapidly. Therefore, when designing an integrated signal, it is necessary to balance both communication information modulation and RSM suppression. The orthogonal amplitude modulation (QAM) OW integrated signal proposed in this paper has high frequency band utilization, which effectively improves the communication rate and frequency band utilization of the OW integrated system.

3. QAM-OW signal model

As an important multi-carrier modulation technique, the basic idea of the OW signal is to convert the high-rate WIMAX serial data stream into a low-rate N-way parallel sub-data stream through serial-to-parallel conversion operation, and respectively to N-channel parallel sub-data. Among the stream modulated N OFDM subcarriers, M_{QAM} QAM modulation is used again for each OFDM subcarrier, where $M_{\mathrm{QAM}}$is a modulation factor. Then parallel transmission is performed. Due to the sub-stream flow rate, it becomes 1/N times the WIMAX data stream. Multi-carrier modulation technology can divide a wide-band frequency selective channel into N narrow channels with narrow bandwidth, which has strong anti-interference and multi-path effects, and is suitable for transmitting wireless data at high rate. In OFDM, subcarriers are orthogonal to each other in the time domain and overlap each other in the frequency domain. Such signal structures have better spectrum utilization and can be effectively separated at the receiving end.

An OFDM radar usually uses one transmit pulse to transmit one OFDM symbol, and s(t) is a single-symbol transmit signal whose expression is:

$$\bar{s}(t)=\sum_{m=0}^{N_c-1} w_n a_{n,m}\, exp(j2\pi m\Delta f t)\cdot rect\left[\left(\frac{t}{T_s}\right)\right] \quad \mathbf{(1)}$$

$$rect[t/T_s]=\begin{cases}1 & ,0\le t\le T_s\\ 0 & ,\text{其他}\end{cases}$$

In this paper, QAM signal modulation is used. Assuming that the QAM real part modulation coefficient is A_S and the imaginary part modulation coefficient is A_X, the corresponding complex amplitude is $|a_n|=\sqrt{A_S^2+A_X^2}$.

When the transmitting carrier frequency is f_Z, the transmission signal is:

$$x(t)=Re\left[\sum_{n=0}^{N-1} w_n a_{n,m} rect(t)\cdot \exp(j2\pi n\Delta f t)\exp(j2\pi f_Z \mathrm{t})\right] \quad (2)$$

Assuming that the space has a target at the distance R and has a radial velocity v, the complex analytical expression of the received m-th frame echo signal obtained by down-conversion to obtain the received signal is:

$$\bar{\mathrm{y}}(t)=\lambda\exp(-j2\pi f_Z\tau)\exp(j2\pi f_d t)\sum_{n=0}^{N-1} w_n a_{n,m}\, rect(t-\tau)\cdot exp[j2\pi n\Delta f(t-\tau)] + g_m(t)\mathbf{(3)}$$

Where: λ is the target scattering coefficient; $f_d=f_Z(\frac{2v}{c})$,is the Doppler shift; c is the speed of light; $g_m(t)$is the Gaussian white noise signal, and its distribution satisfies the Gaussian distribution with a mean of 0 and a variance of σ^2; the delay variation is $\tau=$

2R/c.

Pulse compression of its formula, the output signal is:

$$\chi(\tau, f_d) = \lambda \sum_{n=0}^{N-1} \exp\left[j2\pi(n\Delta f + f_Z)\tau\right] \cdot exp\left[-j2\pi f_d(\frac{n\Delta f}{f_Z} + 1)(T+\tau)\right] \cdot$$
$$\operatorname{sinc}\left[\pi f_d\left(\frac{n\Delta f}{f_Z} + 1\right)(T-\tau)\right] \cdot (T-\tau)|w_n|^2\left|a_{n,m}\right|^2 + L_s \quad (4)$$

Where: L_s represents the output of the noise after passing through the matched filter. The traditional radar signal processing coherent accumulation algorithm directly coherently accumulates signals. For the QAM-OW radar communication integrated system, the shared signal carries the random communication modulation information $a_{m,n}$ To analyze the quantitative characteristics of the random communication modulation information, it is necessary to study the statistical characteristics of the multi-frame signal coherent accumulation. Assuming that the amplitude and phase are uniformly distributed, there are:

$$J\left(\left|a_{n,m}\right|^2\right) = J(A_S^2 + a_X^2) = C \quad (5)$$

Where: J[] represents the mean value; C is the average energy of the WIMAX signal.

4. Simulation experiment

4.1 Fuzzy function analysis

The parameters simulated in this paper are set as follows: the subcarrier coding length is 13, the carrier spacing Δf=10MHz, and the number of subcarriers N=64. $a_{n,m}$ uses 16-QAM. The center carrier frequency f_c=10GHz, the pulse width is T=1.3 μs, and the integrated signal duty cycle is 0.3.

Figure 1 and Figure 2 respectively simulate the two-dimensional matched filter function of the ideal combination of 1 frame radar signal and 1 frame QAM-OW integrated shared signal echo velocity and distance. Comparing the simulation results of FIG. 1 and FIG. 2, it can be found that the side lobes of the shared signal waveform are disordered, and the OFDM radar signal has a regular stripe pattern. This is because the shared signal has different waveforms transmitted between different pulses, and it can well accumulate the target energy in the main lobe range, but its sidelobe characteristics change with the transmitted communication information, showing similar noise. The characteristics that affect the stability of the system.

Then the bit rate can be expressed as:

$$64bit/1.3\mu s \times 0.3 = 14.769\text{Mbit/s}$$

Signal bandwidth B= $N * \Delta f = 640\text{MHz}$, Therefore the spectrum validity is $0.023bit/(s * Hz)$,

The efficiency of the spectrum is determined by the bandwidth of the radar system. If properly designed, the system can achieve a similar bit error rate through a conventional OFDM communication system, and it can be concluded that the integrated signal can meet the communication requirements to some.

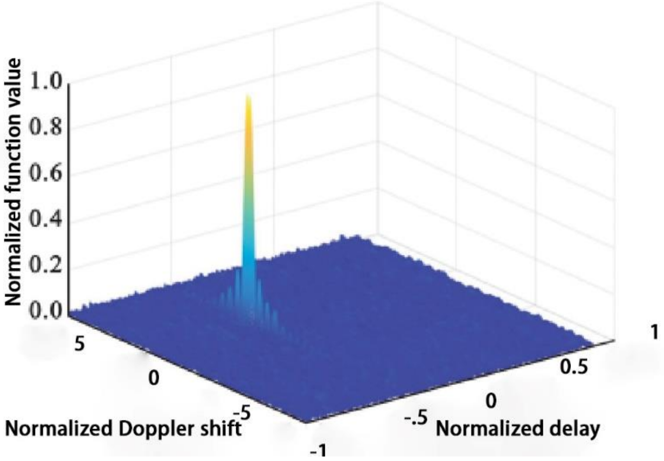

Figure 1: OFDM radar signal

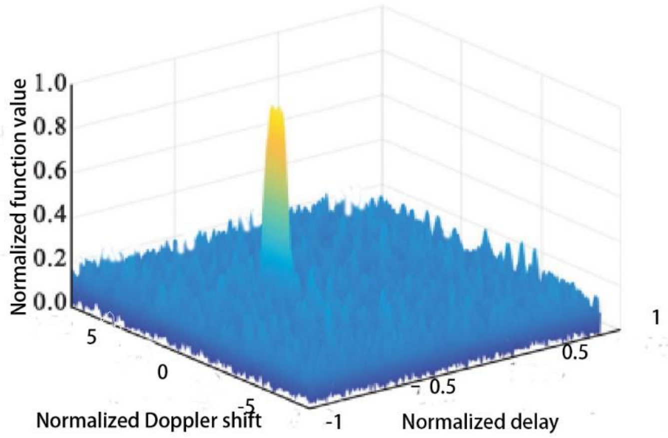

Figure 2: QAM-OW integrated signal fuzzy function

4.2 Performance of the communication system

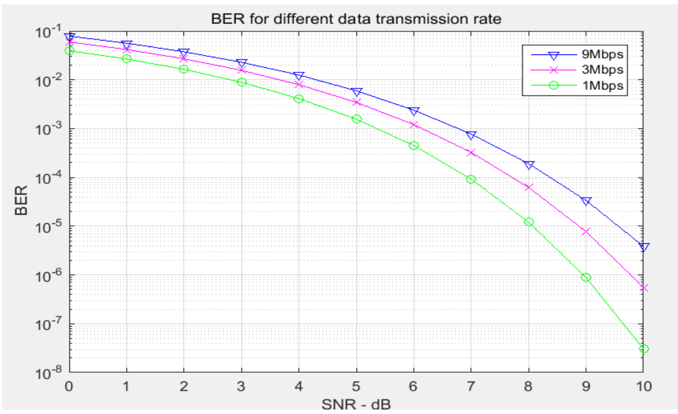

Figure 3: Signal-to-noise ratio and bit error rate of 16QAM-OW signals at different transmission rates

The bit error rate (BER) relative to the signal-to-noise ratio (SNR) in the QAM-OW signal at different data rates is plotted by Figure 3. Obviously, as the data rate increases, the bit error rate increases. This is because encoding at a higher rate reduces the energy-to-noise power spectral density ratio, that is, the data rate can be increased by increasing the encoding rate, but at the same time reducing communication reliability.

4.3 Radar performance analysis

Figure 5 shows the comparison of the signal transmission and noise ratios of the transmission method used in this paper and the traditional radar transmission chirp signal. The traditional radar transmits a chirp signal. The purpose of the simulation here is only to compare the obtained radar echo signal-to-noise ratio at different distances of different transmission modes. It can be seen from the simulation results that with the QAM-OW radar communication integration scheme, the signal-to-noise ratio of the radar increases with the detection target distance under the same pulse width, same pulse repetition period and the same signal bandwidth. Falling faster. However, for marine radars, the adoption of some algorithms, or simply increase the radar's transmit power, can effectively compensate for the decline in the signal-to-noise ratio of the QAM-OW system.

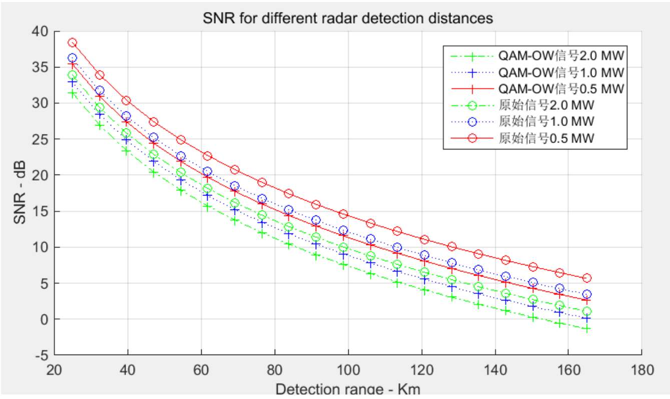

Figure 4: Probing distance and signal-to-noise ratio

5. Conclusion

In this paper, the feasibility study of QAM modulated OFDM signal and WIMAX communication system integration is carried out. First, the expression of the QAM-OW signal is given, and then the feasibility analysis is carried out with the help of the fuzzy function. The theoretical analysis and simulation results show that the integrated signal satisfies the instructions of the QAM-OW communication system. However, since the communication information modulation processing of the radar signal echo is used in this paper, when the carrier speed is too large, the orthogonality between carriers is affected, but for the navigation field, the radial velocity of the ship is small, which is suitable for shipborne Radar communication integration.

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