A New DS/DPSK Underwater Acoustic Communication System

Zhang Gangqiang[1, 2 a], Dong Yangze[1, 2 b]

[1] Science and Technology on Underwater Acoustic Antagonizing Laboratory, Shanghai, China, 201108

[2] Shanghai Marine Electronic Equipment Research Institute, Shanghai, China, 201108

[a]evuj@163.com, [b]dongyangze@139.com

Keywords: Shallow water acoustic channel; DPSK; M-ary DSSS; anti-noise performance

Abstract. For DS/DPSK, carrier synchronization is not necessary in the receiver end, it outperforms DS/PSK systems respect to anti-frequency shift and anti-phase-jitter ability in phase changing shallow water channels, thus is considered as a robust modulation scheme in shallow water mid- and long-range acoustic communications. Traditional M-ary DSSS systems adopt difference of spread sequence, at the receiver end, differential demodulation is carried out first, and then de-spread process is performed, this method results in degradation of anti-noise performance as spreading gain was not utilized during demodulation stage. A novel differential direct sequence spread spectrum system, in which receiving bit decision was made based on sign of peak value of multiplication result of in-phase and quadrature-phase channel cross-correlation functions, is proposed in this paper. This new method is suitable for use in M-ary DSSS systems. The superior performance of this new method compared to traditional differential M-ary DSSS system in Rayleigh fading and phase fluctuating channels was valid via computer simulation.

Foreword

Direct Sequence Spread Spectrum, which being widely used in shallow water acoustic communications due to a series of merits including anti-multipath ability, anti-jamming ability, low probability of detection and simplicity of networking procedure, etc., adopts phase shift keying (PSK) modulation or differential phase shift keying (DPSK) modulation mainly. For DS/PSK system, coherent demodulation is used and carrier frequency synchronization is needed, while for DS/DPSK system, by calculating cross-correlation of sampled signal and carrier modulation signal of local pseudorandom code, then multiplying the correlation result with its one-symbol-delayed duplication, the original digital information can be attained by finding the peak value polarity of multiplication result as it represents relative phase relation of the fore and after symbol. In medium and long range shallow water acoustic channel, the random time-space-frequency change brings about rapid fluctuation of the acoustic signal, DS/DPSK modulation type, in which carrier frequency synchronization is not needed, outperforms DS/PSK in anti-frequency shift and anti-phase-jitter, thus is fit to this channel condition.

In M-ary DSSS systems, DS/DPSK , in which delay multiplication of de-spread result was performed, is no longer suitable, in that adjacent symbols adopt different pseudorandom codes depend on the bits set they carries, which leads to non-correlation of adjacent symbol waveform.[3] presents a method in which differential modulation operation was performed on spread sequence, this method can be applied to M-ary DSSS systems and has the advantage of resisting to the effects introduced by channel phase fluctuation, however, the anti-noise performance was poor because in the receiver end of this method differential demodulation operation was performed before de-spread operation, thus the spread gain cannot be utilized.

In this paper, a new M-ary differential DSSS modulation method was presented, in which the In-phase channel of the transmitter was modulated by bits sequence identically equal to 1 and the Quadrature-phase channel was modulated by transmitting information bits, and in the receiver end the cross-correlation function was calculated on the In-phase and Quadrature-phase channel each, the two cross-correlation functions were then multiplied and then the original digital information can be attained by finding the peak value polarity of the multiplication result. The computer simulation results showed that M-ary DSSS systems adopted this new method outperforms method introduced by [3] in Rayleigh fading and phase fluctuation channel regarding anti-noise capability, concretely, the SNR level required in this new method is 6dB less than in method presented by [3] to achieve the same bit error ratio.

In the rest of this paper, part 2 introduces the principle of the present new differential M-ary DSSS modulation framework; in part 3, computer simulation was carried out and the result was showed; in part 4, conclusion of this paper was drawn.

Theory Introductions

A M-ary differential DSSS framework presented by [3] carried out serial-to-parallel conversion first, and then the pseudo-random code selector chose a pseudo-random code depended on input bits set, the pseudo-random code was then used to modulate the transmitting bits, differential modulation operation was then performed on the spreading bits, at last carrier frequency modulation was performed on the differential sequence to form the transmitting signals. In the receiving end, the received signal was first band-pass filtered and then multiplied with its one-chip-delayed duplicate, the multiplication result was then low-pass filtered to remove its high frequency portion, by carrying out these procedures differential demodulation operation was implemented, the differential demodulation result was then feed into M correlators to perform de-spreading operation concurrently, the original digital information can then be acquired by finding the index of these M correlators having maximal output. As demodulation operation was needed to perform first and this operation was susceptible to noise jamming, the correlation between the spread sequence obtained by demodulation operation and original spread sequence decreases, and thus the bit discrimination process would be affected.

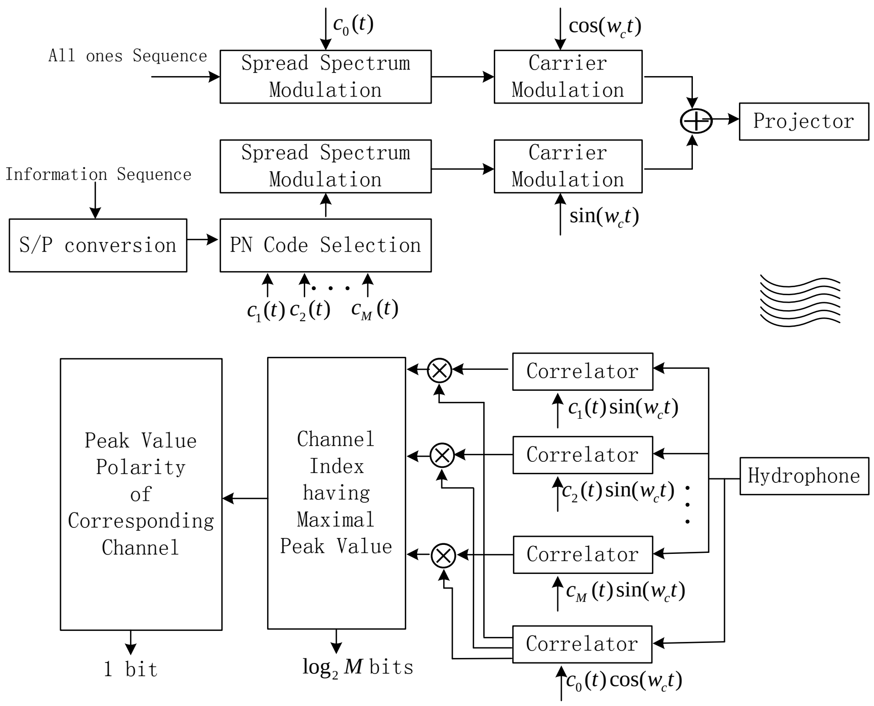

Fig.1 Flow chart of M-ary DSSS system presented in this paper

A novel M-ary differential DSSS method, with transmitter and receiver flow chart shown in Fig.1, was presented in this paper. In the transmitter end, the In-phase channel uses a fixed pseudo-random code to modulate a sequence identically equal to 1, and the Quadrature-phase channel chooses a pseudo-random code from pseudo-random code group depended on the input information bits, the spreading sequence of both channel were then each modulated with quadrature carriers, at last the two carrier modulated signals were mixed and transmitted. In the receiving end, correlation function of the received signal and the In-phase channel reference signal was calculated first, and then correlation function of the received signal and the M quadrature-phase channel reference signals was calculated concurrently. As there are identical main lobe waveform between auto-correlation waveform of carrier modulation signals of different pseudorandom codes having identical bandwidth and carrier frequency, by multiplying M cross-correlation functions of Quadrature-phase channel with cross-correlation of In-phase channel, log2(M) bits can be obtained by finding the index of these M multiplication results having maximal peak value, and 1 bit can be obtained by finding the polarity of the peak value of corresponding channel.

As the In-phase channel and the Quadrature-phase channel undergoing a same channel amplitude fading and phase fluctuation in a given symbol period, when the bit stand for phase of pseudo-random code of the Quadrature-phase channel in the transmission bit group is 1, namely identical to the transmitting bit of the In-phase channel, the sign of the peak value of the multiplication result will always be positive, on the contrary, when the bit stand for phase of pseudo-random code of the Quadrature-phase channel in the transmission bit group is -1, the sign of the peak value of the multiplication result will always be negative, therefore the method adopted in this paper, more specifically, by multiplying the In-phase channel cross-correlation function and the Quadrature-phase channel cross-correlation function, can solve the phase ambiguity problem and has the advantage of excellent anti-phase-jitter ability, furthermore, it outperforms the method mentioned in [3] in anti-noise jamming as de-spreading operation being performed before differential demodulation operation so that the spread gain can be utilized.

Simulation Analysis

Computer simulation of performance of the method present in this paper was done in a simulated shallow water Rayleigh amplitude fading and phase fluctuation channel; the result was being compared with the method mentioned in [3].

At the first step a time-invariant channel model was built using ray theory, the channel impulse response was then computed. For each transmission path, only the Rayleigh amplitude fading effect was added, in this way channel Type Ⅰ was constructed; For each transmission path, the Rayleigh amplitude fading and phase fluctuation effect were both added, in this way channel Type Ⅱ was constructed. These two channel type can be implemented by constructing a complex sequence $x_c + jx_s$, where

$$
\begin{aligned}
x_c(t) &= \left[\sqrt{\tfrac{2}{N_1+1}} \sum_{n=1}^{N_1} \cos(\tfrac{\pi n}{N_1}) \cos\left\{2\pi f_d \cos(\tfrac{2\pi n}{N_2})t\right\} + \tfrac{1}{\sqrt{N_1+1}} \cos(2\pi f_d t) \right] \\
x_s(t) &= \sqrt{\tfrac{2}{N_1}} \sum_{n=1}^{N_1} \sin(\tfrac{\pi n}{N_1}) \cos(2\pi f_d \cos(\tfrac{2\pi n}{N_2})t)
\end{aligned} \qquad (1)
$$

Where $N_2 = N_1 + 4$, f_d is the maximal doppler frequency, for different paths, N_1 and the start time t can be different.

In channel Type Ⅰ condition, when the transmission signal is $s(t)$, the received signal of one of the transmission paths will be $\sqrt{x_c^2 + x_s^2}\,s(t)$; In channel Type Ⅱ condition, when the transmission signal is $s(t)$, the received signal of one of the transmission paths will be $\mathrm{Re}\left[(x_c + jx_s)s(t)\right] = x_c s(t)$.

The top one of Fig.2 shows one of the simulation results of $\sqrt{x_c^2 + x_s^2}$, x_c and the bottom one shows the results of $\sqrt{x_c^2 + x_s^2}\,s(t)$, $x_c s(t)$. In can be seen from Fig.2 that channel Type Ⅰ and Ⅱ both give arise to random fading of signal amplitude, and channel Type Ⅱ also brings about fluctuation of signal phase.

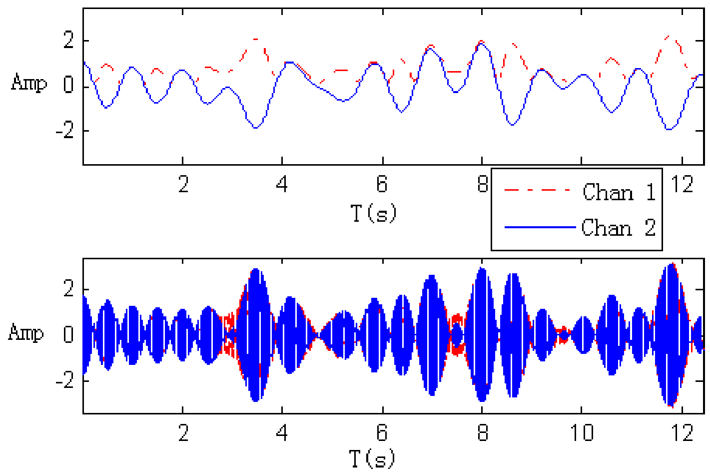

Fig.2 Fading amplitude and time domain signal

Parameters of simulating transmitting signal as follows: carrier frequency 1kHz, pseudo-random code length 127, chip time width 2ms, symbol time width 254ms, doppler frequency 1Hz, Signal-to-Noise ratio from -18dB to 16dB, each symbol contains 4 bits, the first three of them determine which pseudo-random code to be selected and the last one determines phase of the pseudo-random code chosen. During the simulation, bit error ratios of three kind of M-ary DSSS systems, that is, system did not utilize differential modulation (written as Method 1 in the following paper), system performed spreading modulation before differential modulation (Method 2), and system adopted the method presented by this paper (Method 3), were computed, the results under channel Type Ⅰ were shown in Fig.3, and the results under channel Type Ⅱ were shown in Fig.4.

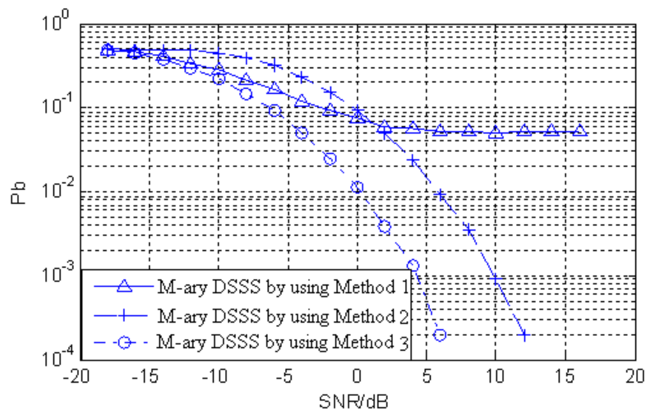

Fig.3 Comparison of P_b of M-ary DSSS methods in Channel Type Ⅰ

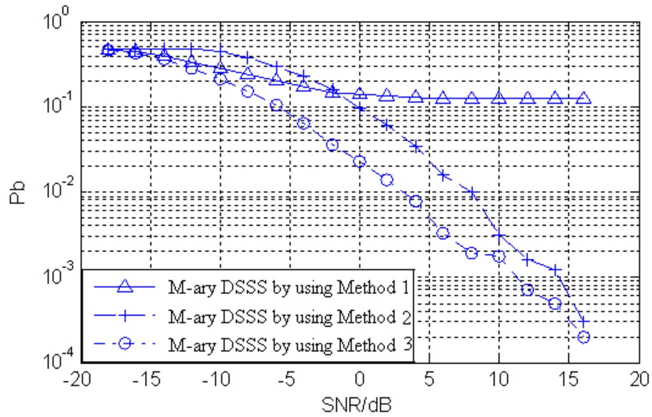

Fig.4 Comparison of P_b of M-ary DSSS methods in Channel Type Ⅱ

As shown in Fig.3 and Fig.4, in only Rayleigh amplitude fading channel, and also in amplitude and phase simultaneously fluctuating channel, the method presented in this paper outperforms the method presented in [3], the minimum SNR to achieve a given BER of the former is 6dB fewer than that of the latter.

Conclusions

Utilization of differential encoding techniques enhances system robustness in shallow water amplitude fading and phase fluctuation channel. Traditional M-ary DSSS system performed spreading modulation before differential modulation, thus was susceptible to noise jamming. A novel method presented in this paper in which decoding was done based on multiplication result of cross-correlation function of In-phase channel and cross-correlation function of Quadrature-phase channel improves the anti-noise performance, the minimum SNR to achieve a given BER of the new method is 6dB fewer than that of the traditional method.

References

[1]Mason S, Zhou S, Yang W B, et al. A comparative study of differential and non-coherent direct sequence spread spectrum over underwater acoustic channels with multiuser interference [M]. IEEE, 2008.

[2]ZHANG Gangqiang. Research On Shallow Water Acoustic Communication Based On Direct Sequence Spread Spectrum Techniques [D].Xiamen University, 2008.

[3]YIN Jingwei. Principles of Underwater Acoustic Communications and Technology of Signal Processing [M]. Beijing:National Defense Industry Press, 2011.

[4]GONG Zaixiao, ZHANG Renhe, et al. Experimental research on sound pulse propagation and channel match in shallow water[J].ACTA ACUSTICA,2005;30(2):108-114.

[5]Harada H, Prasad R. Simulation and Software Radio for Mobile Communications [M].Boston: Artech House, 2002.