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GFDM Based Error Correcting Codes in Underwater Acoustic Channel

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Abstract*: In this paper underwater acoustic communication system based on Coded GFDM (CGFDM) is simulated and the performances are analyzed using different error-correcting codes. And also the parameter selection principle of error-correcting code is evaluated. To build practical and high performance CGFDM system the error-correcting codes from low to relatively high computational complexity, such as, convolutional code, RS code, serial concatenated code of RS code plus convo1utional code and turbo code is evaluated. The parameters of code rate, code length, generation polynomial, interleaving and interleaving matrix length are all considered and analyzed elaborately. Finally, the simulating experiments proved that there are some relative1y low complexities systems based on serial concatenated codes of RS code plus convolutional code that are able to gain better performance as the systems based on turbo code.

Keywords : Turbo code, RS code, convolutional code, serial concatenated code, CGFDM

I. INTRODUCTION

Under Water Acoustic channel is extremely complex and variable time-space-frequency-variant channel. Its narrow channel, strong multipath interference, and severe signal fading [1] have been the main obstacles to high speed transmission of underwater information.

Generalized Frequency Division Multiplexing (GFDM) is a new parallel transmission technology popular in digital communication in recent years. It not only has high spectrum utilization, but also effectively reduces code rate without using complex channel equalization techniques. The inter-symbol interference (ISI) caused by the multipath effect can still be better overcome. For underwater acoustic channel, it is a very attractive technology. However, GFDM does not overcome the channel flat fading , i.e., after signal is transmitted through underwater acoustic channel, the amplitude of each subcarrier still produces reduction in Rayleigh distribution, and some subcarriers are deeply faded, because of completely submerged subcarriers by noise. Therefore, in order to guarantee reliable transmission of GFDM systems in underwater acoustic channels, channel error correction coding must be introduced to further protect the transmission data, i.e., using coded GFDM (CGFDM) technology [2-4].

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II. CGFDM UNDERWATER ACOUSTIC COMMUNICATION SYSTEM

The CGFDM underwater acoustic communication system model is shown in Fig 1. Literature [1] based on a large number of field test data and traditional ray theory analysis, established two kinds of stochastic models for shallow water acoustic channels: for close-range shallow water acoustic channels, it is Rice fading and an additive Gaussian channel Model; for the shallow water acoustic channel in middle and long distance, it is Rayleigh fading and additive Gaussian model. The Rice and Rayleigh channel models assume that the delay and amplitude of each path are determined to be Gaussian-distributed random variables. The mean value is delay of sound line on path, average value of amplitude is amplitude of main sound line on path. In this paper, the Rayleigh fading channel model is used for simulation. The simulation parameters are: propagation distance of 1000m with 6 multipaths.

III. PERFORMANCE ANALYSIS OF CGFDM UNDERWATER ACOUSTIC COMMUNICATION SYSTEM CONSTRUCTED BY ERROR CORRECTION CODING

The following CGFDM underwater acoustic performance is evaluated by non-homogeneous channel coding structure.

A. Convolutional Code

Fig 2 illustrates the performance comparison of CGFDM with conventional codes GFDM. From Fig. 2 it can be observed that the performance of the CGFDM is better under same SNR condition. It can also be observed that with the increase in convolutional code length, the convolutional code performance gain is higher at a higher SNR. It is evident that the coding cost is getting higher and higher at low SNR, and the increase in beam length does not produce a significant effect.

B. RS Code

The RS code is a multi-purpose BCH code [5] based on $GF(2^m)$ domain, each symbol consists of m bits. The decoding process is a multi byte rather than a separate bit, so even an m-bit error can be treated as byte or a symbol error, so RS code correction of sudden errors is not often effective.

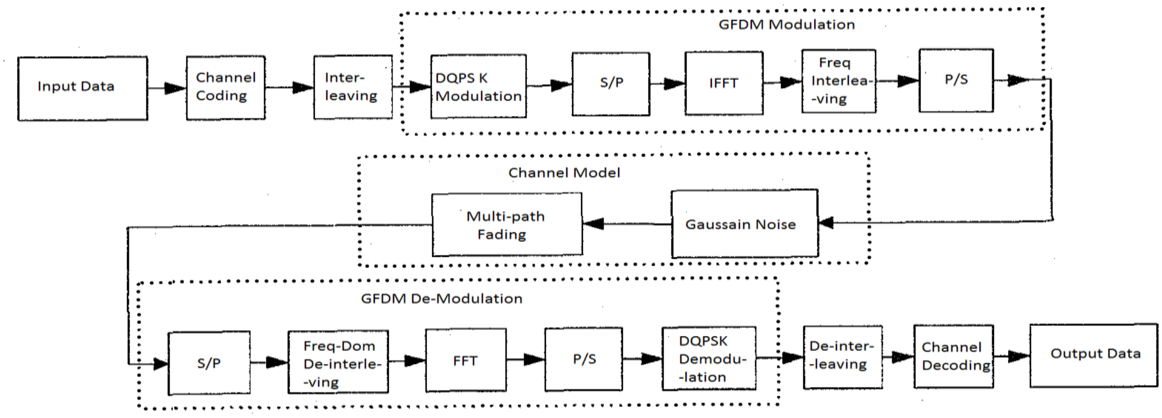

Fig.1: Under water acoustic communication system frame of CGFDM

The RS code is a cyclic code, and its codec can be easily realized by using a shift register to construct a multiplication circuit and a trigger circuit, and has a good algebraic structure, so the decoding method is relatively simple, and the implementation complexity is relatively low. However, due to its long delay in encoding and decoding, the total code decoding delay is much larger than convolutional code. The complexity of RS code decoder decreases as length of packet increases and redundancy decreases, but system resources it needs increase as its packet length increases.

Fig. 3 illustrates performance comparison of several CGFDM systems constructed with different RS codes. As can be seen from Fig. 3(a), under Rayleigh channel, single RS code is superior to convolutional code. As can be seen from Fig. 3(b), RS code length is longer, and increase in signal-to-noise ratio increases faster, but at low signal-to-noise ratio, the code length is shorter and performance is slightly better. Moreover, in order to achieve a substantial improvement in overall performance, it is most feasible to reduce code rate, but in implementation, cost and rate of communication in communication system need to be considered

C. RS + Interleaving + Convolutional, Serial Concatenated code

The serial concatenated code coordinates contradiction between performance and decoding complexity [5]. It uses two short codes to construct a long code, in order to obtain a code with a minimum code distance, which is a good gradual improvement close to Shannon limit code. Since RS code has a good ability to correct burst errors, the outer code or concatenated code selects RS code, while inner code selects fast and efficient convolutional code.

The interleaver [5-6] is added between the inner code and the outer code cascade. The purpose is to spread residual error of signal after outer code as much as possible to make it approximate Gaussian noise. The interleaver is a random interleaver from S=4, which ensures that original adjacent bits are interleaved at least 4 bits apart.

When determining parameters, considering the presence of interleaver, the code length of selected RS code cannot be too short, otherwise interlacing will not bring any effect, which in turn increases cost of system.

At the same time, if code length of outer code is short, the data length coded once for convolutional code is short, and error correction performance brought by one code will be large. Based on these two points, code length of RS code cannot be short, and length of RS code is 127. In the experiment, effects of outer code are different when same inner code is used.

Fig. 4 shows CGFDM system performance diagrams constructed by several different levels of code. Fig. 4(a) shows superior performance of concatenated code. Fig. 4(b) verifies pre-experiment prediction, i.e., outer code length is too short, which reduces error correction performance of inner code convolutional code.

When outer code length is long, constraint length of inner code convolutional code is increased, which can improve overall error correction performance of system. It can be seen from Fig. 4(c) that outer code length is long and its performance does not increase rapidly.

The reason can be obtained from both sides and it can be observed from Fig. 3(b). In this experiment, at a lower signal-to-noise ratio, longer RS code length does not bring about a larger gain.

The second is that RS code is not long enough to cancel inner convolutional code because number of data is smaller than backtracking length L due to increase of bit error.

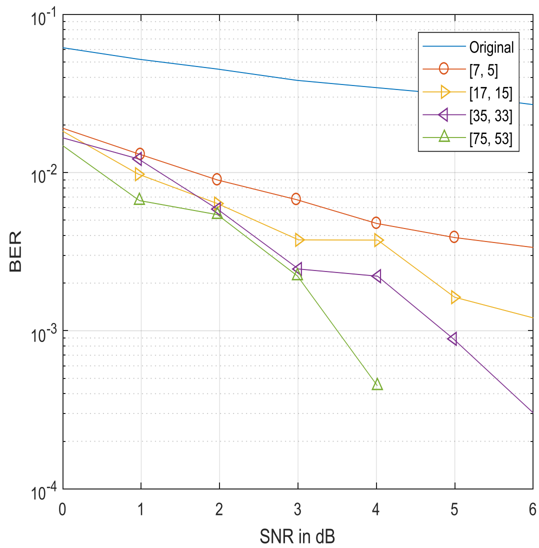

Fig.2: Performance comparison between convolutional code CGFDM and GFDM.

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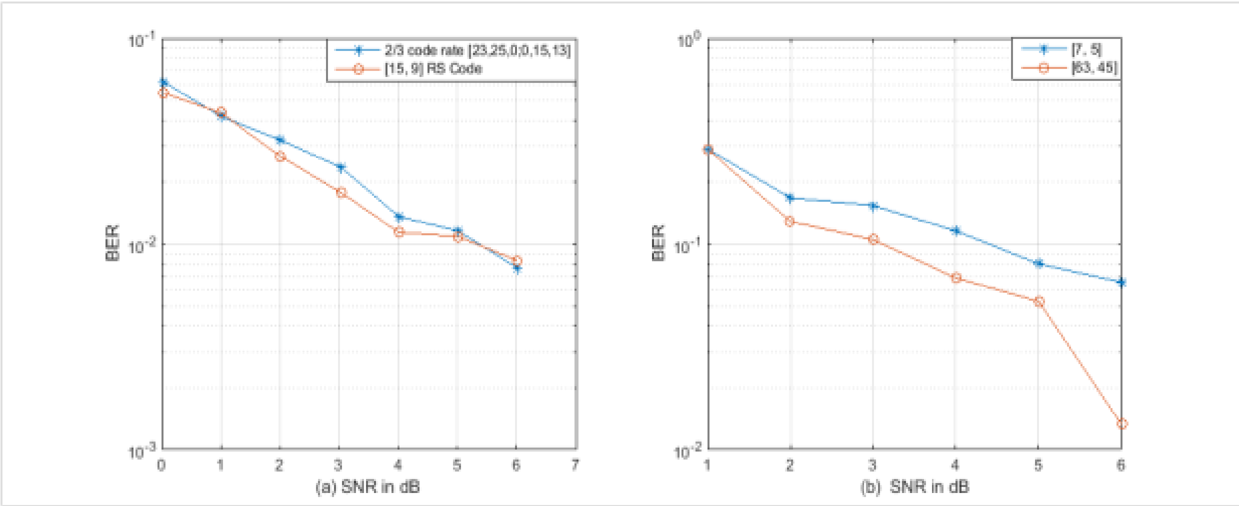

Fig.3: Performance comparison among the systems of CGFDM based on RS code under Rayleigh Channel.
(a) Convolutional code and RS code at similar code rate; (b) RS code with 5/7 code rate and different code length

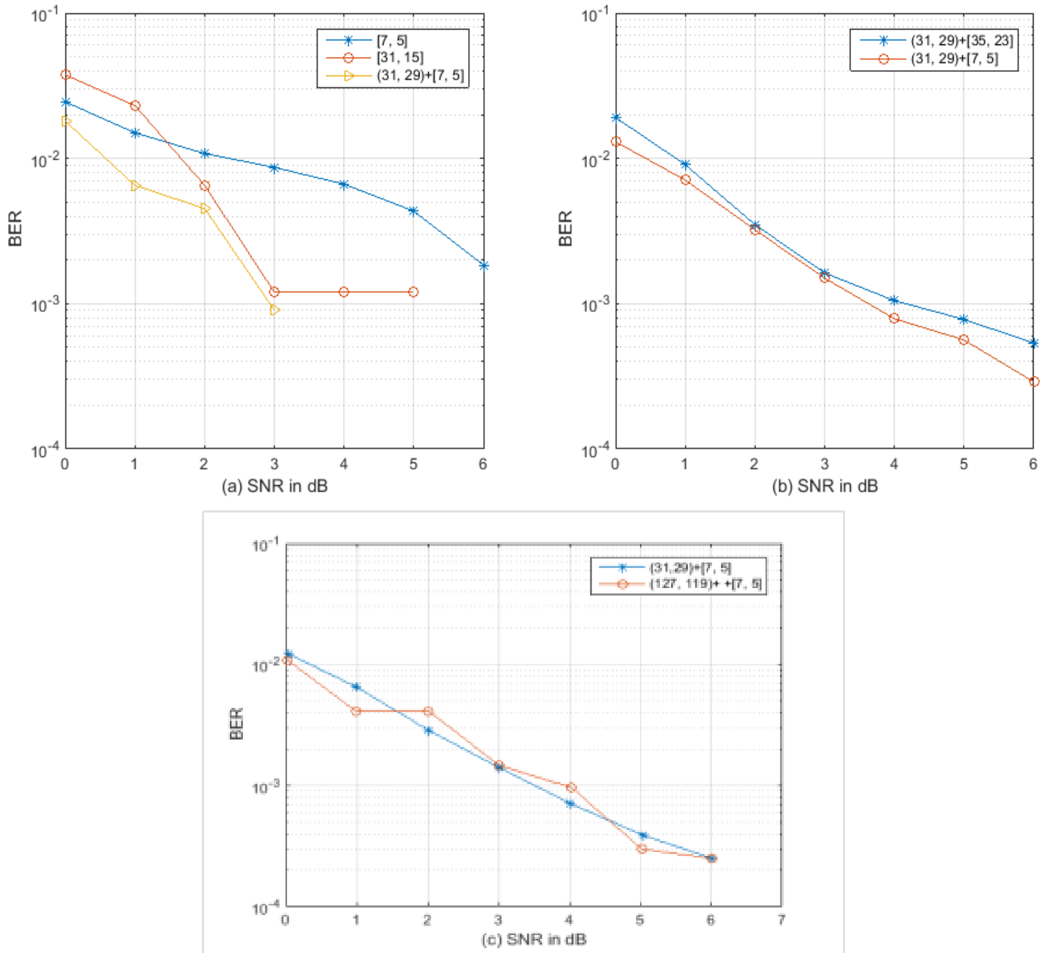

Fig.4 Performance comparison of CGFDM based on serial concatenated code + RS code+ convolutional code
(a) independent RS codes, convolutional codes and concatenated codes; (b) short code lengths Outer code and RS code; (c) Concatenated code with the same inner code and different outer code length

D. Turbo Code

Turbo code is also a concatenated code, called parallel level code. In this experiment, component code is decoded by soft output Viterbi, and decoding is close to maximum likelihood decoding by iterative process. Turbo code uses iterative decoding, and decoding complexity is greatly improved. At same time, a random interleaver is used between two component encoders to disperse error, which makes waiting delay of coding and decoding increase, and system resources are also greatly increased.

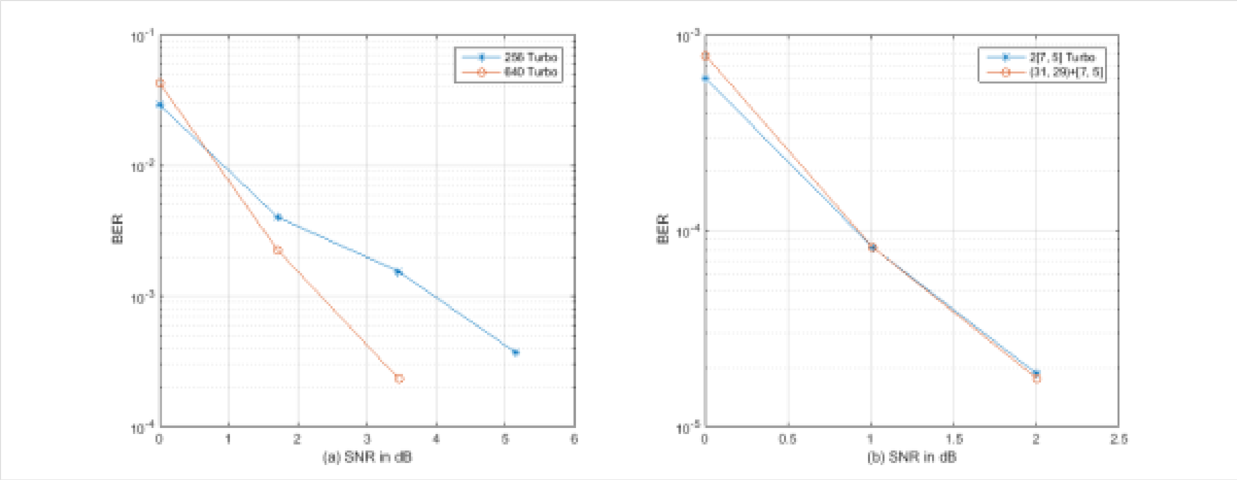

Fig.5: System performance of CGFDM based on turbo code

(a) Comparison of turbo code performance under coded data; (b) Comparison of cascade code and Turbo code performance under similar code complexity)

In this experiment, component coder of Turbo code selects [7, 5] convolutional code, code rate is 1/2, and iteration number is 2. The principle of parameter selection is to select complex low Turbo code as much as possible. Although Turbo code rate is 1/2, since same data needs to be iterated twice to decode, and communication rate is equivalent to ¼ code rate, concatenation code with ¼ rate is also selected here for comparison.

Fig. 5 shows the diagram of CGFDM system constructed by Turbo code. As can be seen from Fig. 5 (a), the amount of coded data is large at one time, and its performance gains faster. The reason is that the amount of coded data is large at one time, and the depth of interleaving between codes becomes larger and performance is improved accordingly. At the same time, its internal convolutional code also increases with amount of coded data once, and decoding performance is correspondingly improved. The reason is explained in the analysis of cascaded code. It can be seen from Fig. 5 (b) that concatenated code and Turbo code have similar overall performance. In this simulation, concatenated code slightly exceeds the Turbo code under 1,00,000 bit of data. Because as SNR is 2, the bit error rate of the concatenated code is 0.

IV. CONCLUSION

From the above experimental results, we can see that each error correction code has its advantages and disadvantages. The key is to find a better balance between system complexity and system performance. In CGFDM system with appropriate system complexity, error correction performance of convolutional code is weaker than RS code, but it can achieve almost real-time performance. The concatenated code performance of RS convolutional code is similar to the Turbo code, but the system complexity is small. In underwater communication, each of shortcomings may cause actual application to stagnate. Therefore, the simulation experiment gives a direction of research. In actual underwater acoustic communication system, the specific parameter selection of each code needs to be determined based on combination of test data and actual underwater acoustic transmission channel.

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