Research on Improved Multilevel Coding Schemes over Rayleigh Fading Channels*

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Abstract-**The performance of improved multilevel coding system with intralevel interleaving and iterative multilevel decoding in Rayleigh fading channels is studied. BCH codes are selected as component codes and code rates are distributed according to "capacity rule". Ungerboeck partitioning scheme and 8ASK modulation are used. The simulation results indicate that interleaving technique and iterative decoding can improve the performance of MLC system greatly.**

I. INTRODUCTION

Multistage decoding (MSD) is a suboptimal technique [1] for the decoding of multilevel codes. The decoding procedure is simple enough to be performed for the simple component codes as in Sayegh [2]. However, in order to achieve large time diversity for improving the performance of multilevel coding (MLC) system in Rayleigh fading channels, the codes will necessarily be more complex. Error propagation from one level to subsequent levels will also happen in the multistage decoding process so that the system performance may degrade greatly.

Interleaving technique can improve the performance of coding system in Rayleigh fading channels by decreasing long-burst errors efficiently [3]. Iterative decoding technique can make further substantial enhancement of system performance by repeated (iterative) applications of the multistage decoder [4]. Therefore, it's of great significance to study the performance of improved multilevel coding schemes, in which simple block codes are used as component codes, with interleaving and iterative multistage decoding in Rayleigh fading channels.

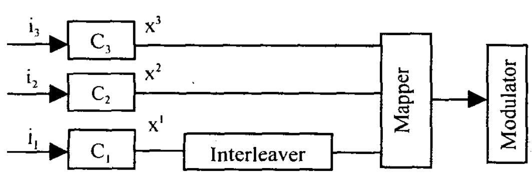

Fig.1. Improved multilever coder with intralevel bit interleaver

In this paper, the performance of improved multilevel coding system with intralevel interleaving and iterative decoding in Rayleigh fading channels is studied and compared with that of the initial system. BCH codes are selected as component codes in MLC system and code rates are distributed according to "capacity rule" [5-7]. Ungerboeck Partitioning (UP) scheme and 8ASK modulation are used. From the simulation results, some significant conclusions can be obtained.

II. IMPROVED MULTILEVEL CODING SYSTEM

To improve the performance of MLC system in Rayleigh fading channels, we propose the improved multistage decoding technique, where the component codes are simple block codes, with interleaving and iterative decoding.

A. Intralevel Bit Interleaver

The position of intralevel bit interleaver is between the coder and mapper in the multilevel coding system. Fig.1

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shows an improved multilevel coder with three levels in the use of an interleaver following code C_1. The effect of interleaving is to reduce the burst length of errors from the first stage decoder thus reducing error propagation. At the receiver, after demodulation, the received symbols are deinterleaved in order to decode the component code C_1.

B. Iterative Decoding

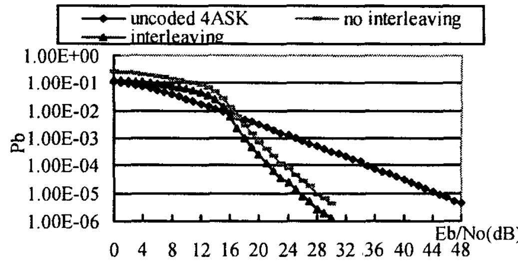
In addition to the use of interleaver/deinterleaver pairs in between the decoding stages, further substantial enhancement of the decoding can be made by repeated (iterative) applications of the multistage decoder. This is equivalent to assuming that decisions after the first round of decoding of code C_1, C_2 and C_3 are only tentative. At the second iterative of decoding, C_1 is decoded assuming that decisions on C_2 and C_3 are correct and then results in an updated decoding of component code C_1. C_2 is now decoded assuming that decisions on C_3 obtained after first stage of decoding, and the updated decisions on C_1 obtained after second stage of decoding are correct. Typically, performance close to optimal decoding can be obtained after only a few decoding iterations.

III. The Performance of MLC System with Interleaving Technique and Iterative Multistage Decoding

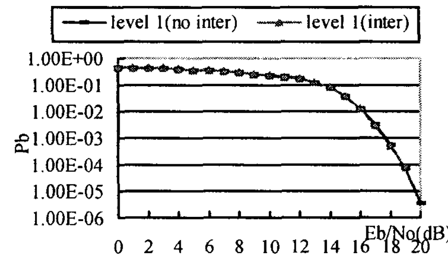
According to the calculation results for capacities of equivalent channels in MLC system with three levels and 8ASK modulation over Rayleigh fading channel [8], and the code rates for designing optimum MLC schemes based on "capacity rule" (total rates is 2 bits/symbol) [9], the performance of MLC/MSD system with interleaving technique and iterative multistage decoding is studied and compared with that of the initial MLC system. BCH codes with code lengths of 127 are chosen as component codes and UP scheme is used.

A. The Performance of MLC System with Intralevel Bit Interleaving

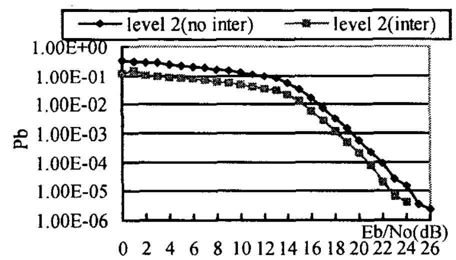
Simulation results are shown in Fig.2~Fog.6. Fig.2 shows the performance comparison for total bit error rates (BER) after interleaving. Fig.3~Fig.5 show the difference in performance for level 1, level 2 and level 3, respectively.



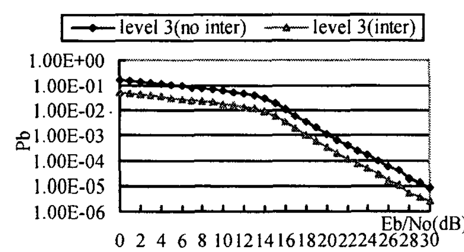
C0(127,36,15);C1(127,99,4); C2(127,120,1)
Fig.2. Rayleigh channel, 8ASK, UP, MLC/MSD, Performance improvement due to interleaving



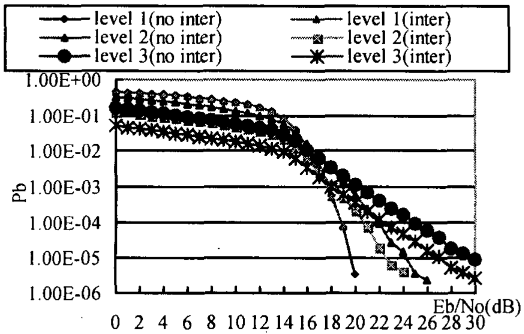
C0(127,36,15);C1(127,99,4); C2(127,120,1)
Fig.3. Rayleigh channel, 8ASK, UP, MLC/MSD, Performance improvement of level 1 due to interleaving



C0(127,36,15);C1(127,99,4); C2(127,120,1)
Fig.4 Rayleigh channel, 8ASK, UP, MLC/MSD, Performance improvement of level 2 due to interleaving



C0(127,36,15);C1(127,99,4); C2(127,120,1)
Fig.5 Rayleigh channel, 8ASK, UP, MLC/MSD, Performance improvement of level 3 due to interleaving



C0(127,36,15);C1(127,99,4); C2(127,120,1)
Fig.6 Rayleigh channel, 8ASK, UP, MLC/MSD, Performance improvement of individual levels due to interleaving

Fig.6 is the combination of Fig.3, Fig.4 and Fig.5 to show the property of unequal error protection (UEP) for individual levels in MLC system. From the simulation results, we can see:

(1) Interleaving technique can improve the performance of MLC system in Rayleigh fading channels. As Fig.2 shows, when $Pb=10^{-5}$, the MLC system with interleaving technique has coding gain of 2.5 dB compared with the initial MLC system and has coding gain of about 19 dB compared with uncoded 4ASK system which has the same bandwidth efficiency.

(2) As show in Fig.3, there is nearly no performance improvement for level 1 in MLC system when the interleaver is only used at the first level. But the effect of interleaving reduces the burst length of errors from the first stage decoder thus reducing error propagation, the performance improvement of level 2 and level 3 in MLC system is obvious. As shown in Fig.4 and Fig.5, when $Pb=10^{-5}$, the performance of level 2 with interleaving is about 2 dB better than the performance of level 2 without interleaving, while level 3 with interleaving has coding gain of about 3dB.

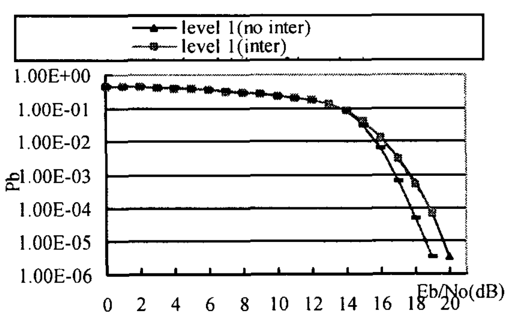
(3) As shown in Fig.6, the performance of level 2 is about 5.5 dB better than the performance of level 3, while the performance of level 1 is about 5 dB better than that of level 2 above a BER of 10^{-5}. Therefore, from the point of view of "unequal error protection (UEP)", the first level has highest protection degree so that we should transmit the most important data at this level. The third level should transmit the least important data with lowest protection degree.

(4)The three levels have different performance improvement with interleaving technique. The level with worse initial BER performance has better improvement. As shown in Fig.6, when $Pb=10^{-5}$, the performance of level 2 after interleaving is about 4.5dB (<5.5dB) better than level 3, while level 1 has coding gain of 3dB (<5dB) compared with level 2 after interleaving. Therefore, applying interleaving technique make the UEP property weaken and tend to equal error protection property.

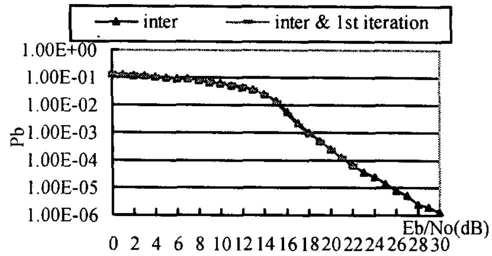
B. The Performance of MLC System Applying Iterative Multistage-decoding

The following we'll study the performance improvement of MLC system of combining interleaving technique with iterative multistage decoding. Simulation results are shown in Fig.7~Fig.9. Fig.7 shows the performance improvement for level 1 in MLC system with three levels when applying interleaving technique and first iterative decoding. Fig.8 shows the improvement of total BER due to iterative decoding for multilevel codes. Fig.9 shows the performance improvement for level 2 in MLC system using interleaving with second iterative decoding. From the simulation results, we can see:

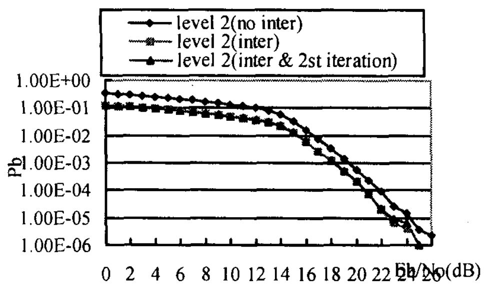
(1) The performance improvement of level 1 in MLC system is obvious by using iterative multistage decoding. As shown in Fig.7, when $Pb=10^{-5}$, the MLC system combining interleaving with iterative decoding can have better performance of about 1.2 dB compared with the MLC system



C0(127,36,15);C1(127,99,4); C2(127,120,1)
Fig.7 Rayleigh channel, 8ASK, UP, MLC/MSD, Performance improvement of level 1 due to interleaving and iterative decoding



C0(127,36,15);C1(127,99,4); C2(127,120,1)
Fig.8 Rayleigh channel, 8ASK, UP, MLC/MSD, Performance improvement due to interleaving and iterative decoding



C0(127,36,15);C1(127,99,4); C2(127,120,1)
Fig.9 Rayleigh channel, 8ASK, UP, MLC/MSD, Performance improvement of level 2 due to interleaving and iterative decoding

only with interleaving technique. Therefore, the data transmitted at this level can obtain higher protection degree.

(2) As shown in Fig.8, the total BER of MLC system has no improvement because the first iterative decoding only improve the first level of MLC system and has no influence to level 2 and level 3.

(3) As shown in Fig.9, the performance of level 2 in MLC system combining interleaving with second iterative decoding has no improvement but degrades slightly when E_b/N_0>22dB compared with the system only with interleaving. Because we only use interleaver at the first level in MLC system and we apply hard-decision decoding method, the information of other two levels used by level 2 after second iterative decoding has worse reliability. From Fig.7 and Fig.9, we can see that iterative multistage decoding can only be used combining with interleaving technique, the MLC system has performance improvement.

IV. CONCLUSIONS

From simulation results and discussions, some conclusions can be got:

(a) The performance of MLC system with intralevel bit interleaver at the first level improved greatly compared with that of the system without interleaving technique.

(b) The MLC/MSD systems with different code rates distribution schemes have different Unequal Error Protection degree to individual levels. Interleaving technique has different influence for performance improvement to different levels. The level with worse initial BER performance has better improvement.

(3) The performance improvement of level 1 in MLC system is obvious by using iterative multistage decoding. But iterative multistage decoding can only be used combining with interleaving technique, the MLC system has performance improvement.

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