상관 레일레이 페이딩 채널에서 수정된 터보 부호 구조를 갖는 Gray 부호화된 16-QAM의 성능

현광민*

요약

본 논문에서는 상관 레일레이 페이딩 채널에서 간단히 수정된 터보 부호 구조를 제안하고, 이것과 같이 사용된 16-QAM의 성능을 분석한다. 기존 터보 부호기에 입력되는 $2N$개의 정보 비트열을 1회의 RSC 부호화 과정을 거쳐 $2N$개 비트들로 구성된 단일 패리티 열을 얻는 대신, 제안한 구조에서는 입력 정보 비트열을 2개의 그룹으로 나누어 독립적으로 RSC 부호화함에 따라 2회에 걸쳐 2개의 N개 비트들로 구성된 2개의 패리티 비트열을 얻도록 한다. 수신기에서 반복 복호를 수행할 때, 두 개의 독립적으로 RSC을 이용하여 부호화하여 송신된 패리티 비트열을 각각 복호한 후 연결시키고 이 결과를 기존 복호기와 마찬가지로 반복 복호에 적용한다. 제안된 구조를 이용할 경우 기존의 터보 부호와 호환성을 유지하면서, 상대적으로 높은 도플러 스펙트럼이 존재하는 경우에 성능이 개선된다.

Performance of Gray Coded 16-QAM with Modified Turbo Code Structure over Correlated Rayleigh Fading Channel

Kwangmin Hyun*

ABSTRACT

In this paper, we propose a simply modified Turbo coding structure and investigate its performance in conjunction with Gray coded 16-quadrature amplitude modulation (QAM) over correlated Rayleigh fading channel. Instead of conventional Turbo encoder producing a single parity stream of bits after single operation of a RSC encoder using information bits, the modified Turbo encoder outputs two independent bit parity streams after two times operation of RSC with information bits divided into two streams with bits for each. During iterative decoding at the receiver, the received two independently RSC coded parity streams are independently decoded and apply for this process after constituting these streams to a single stream like the conventional structure. With the proposed structure, we can obtain not only improved decoding performance in moderate/high Doppler spectrum but also compatibility with conventional Turbo code structure.

Key Words : Iterative decoding, Turbo code, Correlated fading, Gray Mapping, 16-QAM

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Ⅰ. Introduction

In many mobile scenarios for wireless communications, the channel is subject to fast fading due to high velocities of the mobile station, each incoming signal through different paths will experience a frequency change called as Doppler shift. The Jakes fading model simulating time-correlated Rayleigh fading waveform [1] is still widely used today.

The turbo encoder, introduced by Berrou, et al. [2], consists of two or more recursive systematic convolutional(RSC) encoders separated by interleavers generating it's own parity stream. The decoder uses an iterative soft-decoding with soft-input soft-output (SISO). For the turbo coding schemes in [3], it is analysed the relationship between block interleavers and coherence times.

The main novel contributions of our work in this letter are that we propose a modified Turbo code and investigate it's decoding performance in conjunction with Gray coded 16-QAM over correlated Rayleigh Fading using the advantage of the inherent unequal protection characteristic, different gain to each bit group in a symbol during Gray mapping.

II. Encoder Structures

When we use the conventional $1/3$ Turbo code with the information length of $2N$, the total amount of bits to transmit are $6N+\alpha$, where α is the number of tail bits of RSCs and here we ignore this value for simple notation because it is relatively small comparing to the total amount of bits.

For quadrature modulation, the encoded bits of $6N$ are divided equally into two sub-streams for in-phase(I) and quadrature(Q) axis with the length of $3N$ for each, and mapped on the constellation.

<Fig. 1> shows the detailed block diagram for the proposed Turbo encoder structure, where S/P is serial to parallel converter and the numbers in the parentheses are the number of bits.

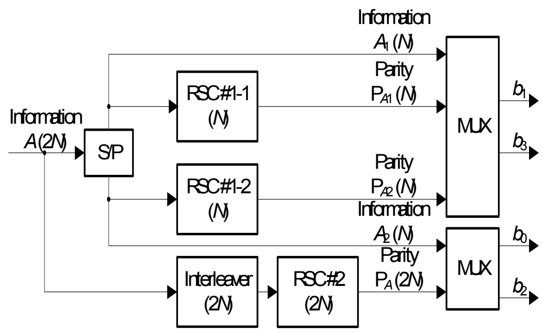

그림 1. 수정된 터보 부호화기의 구조
Fig. 1. The Structure of the modified Turbo encoder

In the proposed structure, when we send a information (A) block with length of $2N$, first we divide this information into two small blocks(A_1, A_2). And then each block is passed through single RSC in sequence or independent two RSCs in parallel generating two short parity stream of N bits for each, (P_{A_1}, P_{A_2}). At the same time, the other RSC with the interleaved original $2N$ information by the $2N$-depth interleaver generates a long parity stream of $2N$ bits (P_A). Then we group these streams into two, $group_1=\{A_{2,}P_A\}$ and $group_2=\{A_{1,}P_{A_1},P_{A_2}\}$ with the same bit length of $3N$ for each group.

We allocate $group_1$ to high-gain bits among the bits in a Gray coded symbol and $group_2$ to low-gain bits via MUX(multiplexer), assuming that the parity stream P_A in

$group_1$ is more important than other parity streams in $group_2$, P_{A_1} and P_{A_2}. That is, a symbol of Gray coded 16-QAM is consisted with 4 bits, $\{b_{0,} b_1\}$ on I axis and $\{b_{2,} b_3\}$ on Q axis, then there exist two different bit gain groups inherently, high and low, and we assume one of 2 bits on I and Q axes (in here b_0, b_2) has higher gain than the other bits(b_1, b_3). Thus, the $group_1$ is loaded to b_0, b_2 and the $group_2$ to b_1, b_3 with the same amount of bits for each.

III. Decoder Structures

The received Gray coded 16-QAM signal is demodulated and converted to one of soft bit values in set $\{rb_0, rb_1, rb_2, rb_3\}$.

<Fig. 2> shows the detail decoder structure, where Int., Deint., and DEMUX are interleaver, deinterleaver, and demultiplexer, respectively.

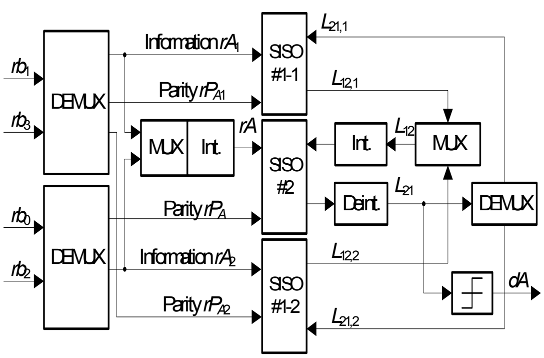

그림 2. 수정된 터보 복호화기의 구조
Fig. 2. The Structure of the modified Turbo decoder

After finishing the first decoding step with two pairs of received information and parity, $\{rA_1,\ rP_{A_1}\}$ and $\{rA_2, rP_{A_2}\}$, at SISO #1-1 and SISO #1-2 respectively, the extrinsic information L_{12},formed by merging the respective extrinsic values $L_{12,1}$ and $L_{12,2}$ produced by the SISOs, is interleaved and fed into SISO #2 via MUX to perform the second decoding step.

At the same time, the merged information rA = $[rA_1\ rA_2]$ and the received parity rP_A are also input to SISO #2. The decoded output, the deinterleaved extrinsic value L_{21} of SISO #2, is separated into $L_{21,1}$ and $L_{21,2}$ corresponding to rA_1 and rA_2 to feed back to SISO #1-1 and #1-2 for next iteration. After final iteration, the extrinsic information L_{21} of SISO #2 is converted to hard decision bit value dA . To reduce the complexity, we can remove either SISOs #1-1 or #1-2 with serial processing, decoding one after another in sequence.

IV. Simulation Results

Here we verified the effectiveness of the proposed structures using average bit error rate (BER) performance with simulation because of hardness of driving analytical results.

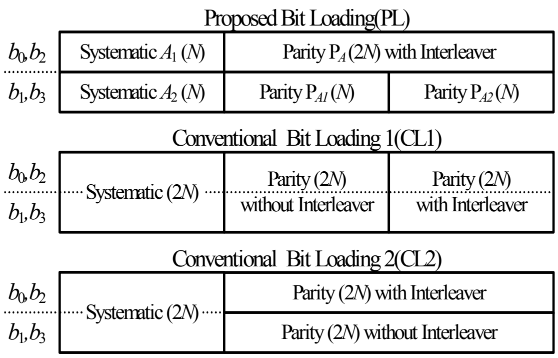

그림 3. Bit 할당 비교

Fig. 3. Bit Loading for Comparison

For fair comparisons between the proposed and the conventional Turbo codes, we used two types of bit loading methods for the conventional one, CL1 and CL2, considering inherent two different gain bit groups of Gray coded 16-QAM as shown in <Fig. 3> With Gray coded 16-QAM, we remember that $\{b_0, b_2\}$ and $\{b_1, b_3\}$ are classified as high- and low-gain bit groups, respectively.

For channel and Turbo code parameters in this simulation, we use the fading generator with DFT in [4], the RSC polynomial G = [1,15/13], maximum iteration = 8, random interleaver depth(information bits for Turbo code) = 6,144 bits, and the normalized Doppler frequency, $f_{dn}=f_{dT_s}$ of {0.01, 0.05, 0.005}, where f_d and $f_s = 1/T_s$ are Doppler and sampling frequencies respectively.

Also we assume coherent demodulation with perfect channel estimation. In <Fig. 4>, the plots reveals that the proposed structure(PL) could obtain more gain than that of the conventional ones (CL1 and CL2) with rapid performance improvement(circle to triangle and square).

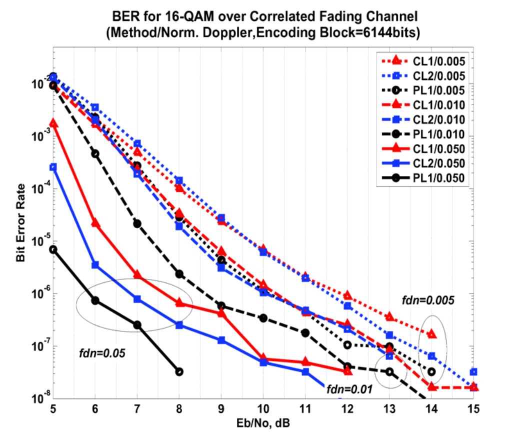

그림 4. BER 성능

Fig. 4. BER performance

<Table 1> shows the resultant gain of PL comparing to the most commonly used bit loading method CL1 at BER of 10^{-5} and 10^{-6} each with the given f_{dn}.

표. 1. PL과 CL1을 비교한 E_b/N_0 이득

Table.1. E_b/N_0 gain of PL comparing to CL1

Gain(dB)	$f_{dn}=0.05$	$f_{dn}=0.01$	$f_{dn}=0.005$
BER=10^{-5}	1.5	1.4	1.1
BER=10^{-6}	1.8	1.6	1.5

For different f_{dn} (different line types), as expected, lower values of f_{dn} show worse performances. For the different bit loading performance comparison between CL1 and CL2 with the same conventional structure, CL2(square) has better performance than that of CL1(triangle) for higher f_{dn}.

With this result, it is worth noting that higher gain to the whole parity stream, generated with interleaved information, reinforces the capability of mitigating correlated fading effects.

Further more, with the same reason, the proposed structure (PL) not only outperforms the conventional ones but also reaches to the error floor early at lower E_b/N_0.

It is presumed that under relatively worse signal condition(low-gain bits always have less gain than high-gain bits), smaller length of codeword has more chance to improve their own signal quality than longer one preventing from the negative effects with strong probability. However, it does not directly mean that, even the better performance with higher fdn value, channel status is always better than lower fdn environment. Also f_{dn} is closely related to channel estimation performance and complexity, compensating for the rapid phase variations of the fading process.

V. Conclusion

In this paper, we have proposed a simply modified Turbo coding structure and investigate its performance in conjunction with Gray coded 16-QAM over correlated Rayleigh fading channel. The conventional Turbo encoder which produces two independent parity streams with two RSCs, the output parity stream of one RSC with information and that of another RSC with information through an interleaver. But the modified Turbo encoder outputs two independent bit parity streams after two times operation of RSC with information without an interleaver, information bits divided into two streams with bits for each.

The proposed structure provided not only better performance than the conventional one in moderate/high f_{dn} but also operational compatibility with the conventional Turbo code by changing the original structure with MUX and DEMUX using proper signal path control.

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