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Propose and Performance Analysis of Turbo Coded New T-DMB System

Hanjong Kim
School of Electrical, Electronics and Communication Engineering

터보부호화된 새로운 T-DMB 시스템 제안 및 성능 분석

김한종
한국기술교육대학교 전기전자통신공학부

Abstract The DAB system was designed to provide CD quality audio and data services for fixed, portable and mobile applications with the required BER below 10^{-4}. However for the T-DMB system with the video service of MPEG-4 stream, BER should go down 10^{-8} by adding FEC blocks which consist of the Reed-Solomon (RS) encoder/decoder and convolutional interleaver/deinterleaver. In this paper we propose two types of turbo coded T-DMB system without altering the puncturing procedure and puncturing vectors defined in the standard T-DMB system for compatibility. One(Type 1) can replace the existing RS code, convolutional interleaver and RCPC code by a turbo code and the other one (Type 2) can substitute the existing RCPC code by a turbo code. Simulation results show that two new turbo coded systems are able to yield considerable performance gain after just 2 iterations. Type 2 system is better than type 1 but the amount of performance improvement is small.

Key Words : T-DMB, RCPC, Turbo code, Compatibility, Turbo Coded T-DMB

요 약 Eureka 147 디지털오디오방송(DAB) 시스템은 CD 품질의 오디오 전송을 위하여 유럽에서 개발되었으나 한국에서는 이러한 DAB 시스템을 기반으로 하여 오디오뿐 만 아니라 비디오 신호도 전송할 목적으로 지상파 디지털 멀티미디어방송(T-DMB) 시스템을 개발하였다. 이러한 T-DMB 시스템의 성능 향상을 목적으로 본 논문에서는 양립성을 위해 기존 T-DMB 시스템 표준안에 정의된 펑쳐링 절차와 펑쳐링 벡터를 이용하면서 터보 부호가 적용된 2가지 형태의 새로운 터보부호화된 T-DMB 시스템 모델을 제시한다. 첫 번째 모델 (Type 1)은 기존의 RS 코드, 콘볼류션 인터리빙, RCPC 코드를 터보코드로 대체시킨 것이며 두 번째 모델(Type 2)은 기존 RCPC 만을 터보부호로 대체시킨 모델이다. 시뮬레이션 결과 제안된 모델은 단지 2회 반복만으로도 상당한 성능 향상을 얻을 수 있음을 알 수 있었으며 또한 두 번째 모델은 첫 번째 모델에 비해 약간 우수한 성능을 보이고 있다.

주제어 : T-DMB, RCPC, 터보부호, 양립성, 터보부호화된 T-DMB

1. Introduction

Since the Eureka 147 Digital Audio Broadcasting (DAB) system was announced in the middle of 1990s in Europe, a large variety of applications have been introduced in many countries in the world. In South

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Corresponding Author: Hanjong Kim(Korea University of Technology and Education)
Email: hjkim@koreatech.ac.kr

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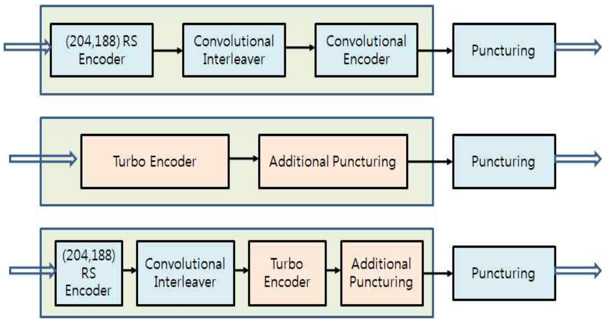
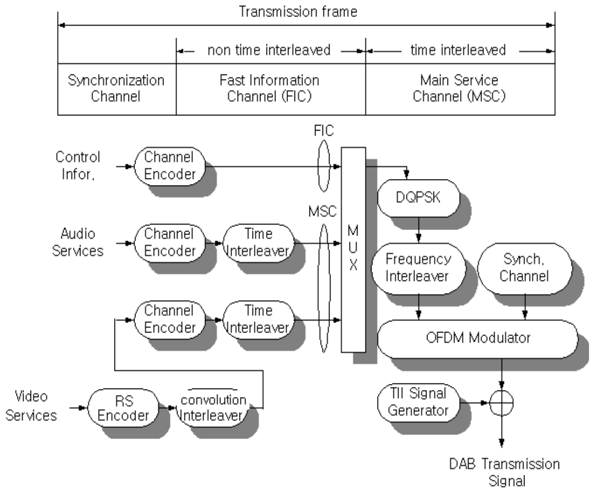
Korea Terrestrial Digital Multimedia Broadcasting (T-DMB) system was developed in the hope that it can support video stream in the DAB ensemble. Since the T-DMB system was based on the DAB system, it includes extra functional blocks which compose of the MPEG-4 format to MPEG-2 format converter and the forward error correction (FEC) blocks to achieve better bit error rate (BER) performance[1][2][3]. With the FEC blocks which consist of the Reed-Solomon (RS) encoder/decoder and convolutional interleaver/deinterleaver, we can obtain a BER rate below 10^{-8} for video service[4]. In order to achieve this lower error rate, we propose two types of turbo coded T-DMB system models as shown in Fig. 1. One model(Type 1) replaces the existing RS codec, interleaver/deinterleaver block and RCPC(Rate Compatible Punctured Convolutional Code) codec by a turbo codec without modifying the puncturing procedure and puncturing vectors defined in the T-DMB system for compatibility. The other one (Type 2) replaces the RCPC codec by a turbo codec. The performance of turbo coded systems is compared with that of standard system under the Rayleigh fading channel.



[Fig. 1] Proposed turbo coded encoder

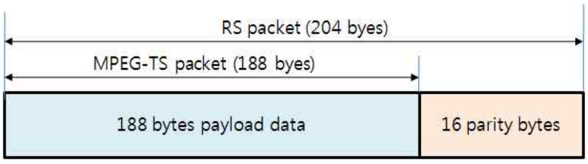


[Fig. 2] Block diagram of standard T-DMB system

2. Structure of the T-DMB System

The DAB system was designed to provide CD quality audio and data services with the required BER below 10^{-4}. To obtain this kind of BER, only rate compatible punctured convolutional code was adapted. However for the T-DMB system with the video service of MPEG-4 stream, BER should go down 10^{-8} by adding FEC blocks. The detail of additional FEC blocks as well as convolutional code block is shown in Fig. 2.

For video service additional FEC blocks which consist of RS code and convolutional interleaver are needed to achieve lower error rate. As the RS code RS(204,188,8) is used which is a shortened form of RS(255,239,8). This RS code is defined in Galois field GF(2^8). The length of each MPEG-2 TS packet input to the RS encoder is 188 bytes and 16 parity bytes are added to make 204 bytes of output packets. The convolutional interleaver uses 12 branches and plays a role in distributing burst errors randomly at the T-DMB receiver. The structure of an RS packet is shown in Fig. 3.



[Fig. 3] Structure of an RS packet

Control Information in the FIC(Fast Information Channel) and video, audio and data services in the MSC(Main service channel) are encoded by means of RCPC codes with code rates available from 8/32, 8/31, ⋯, 8/9. RCPC encoding allows the application of equal and unequal error protection profiles(EEP, UEP), as wll. Then, time interleaving over several symbols (interleaving depth : 384ms) is adopted in the MSC to overcome the time selectivity of the mobile channel. No time interleaving is adopted for the FIC, because the control data is necessary for demultiplexing and decoding of the MSC part in each transmission frame. The coded and time interleaved bits are paired into dibits and mapped on the QPSK symbols. The QPSK symbols are re-ordered over the wideband multicarrier set to overcome the frequency selectivity of the mobile channels by means of frequency interleaving (interleaving depth : 1.536MHz). Then, π/4 shift DQPSK modulation is applied to the QPSK symbols on each subcarrier. Virtual carriers are then padded with zeros to make the number of subcarriers per symbol become a power of 2 and applied to an IFFT which performs the OFDM modulation. The guard interval is inserted at the transition between successive symbols to absorb the intersymbol interference(ISI) created by multipath in the channel. After being sent through the mobile channel, the COFDM received signal is first synchronized and demodulated with a FFT. The data on each subcarrier are then differentially decoded and deinterleaved in frequency and in time. The output of the deinterleaver is quantized before being fed to the Viterbi decoder. Soft decision Viterbi decoding is performed to correct the random errors. For video service video signals go through additional blocks which consist of convolutional deinterleaver and RS decoder to lower the BER further.

3. RCPC Codes of the T-DMB System

The channel coding process for DAB system is based on RCPC coding, which allows both equal and unequal error protection (EEP, UEP), matched to bit error sensitivity characteristics. RCPC coding generates from a vector $(a_i)_{i=0}^{I-1}$ of I bits the resulting codeword $(b_i)_{i=0}^{M-1}$ of M bits. As a mother encoder, a rate 1/4 convolutional code with constraint length 7 and octal polynomial(133, 171, 145, 133) is used [2]. The mother convolutional code generates from I information and six tail bits a codeword $(x_{0,i}, x_{1,i}, x_{2,i}, x_{3,i})_{i=0}^{I+5} = (u_i)_{i=0}^{4I+23}$. The codebits generated by mother code are not transmitted by the puncturing procedure. The first 4I bits $(u_i)_{i=0}^{4I-1}$ generated from I information bits are split into consecutive blocks of 128 bits. Each block is divided into four consecutive sub-blocks of 32 bits. All sub-blocks belonging to the same block are punctured by the puncturing vector V_{PI}, given by the value of the puncturing index(PI). Each index PI corresponds to a puncturing vector V_{PI} , denoted by

$$V_{PI} = (v_{PI,0}, v_{PI,1}, \cdots\cdots, v_{PI,i}, \cdots\cdots v_{PI,31}) \qquad (1)$$

where $V_{PI,i}=1$ connotes that the corresponding bit is transmitted and $V_{PI,i}=0$ indicates a deleted position. The values of the puncturing vectors are given in Table 1, where the value of the code rate 8/(8+PI) is also given. The puncturing procedure allows the effective code rate to vary between 8/9 and 1/4. The last 24 bits $(u_i)_{i=4I}^{4I+23}$ coded by six tail bits are also punctured using the puncturing vector given by

$$V_T = (1100\ 1100\ 1100\ 1100\ 1100\ 1100) \qquad (2)$$

The resulting 12 bits are called punctured tail bits.

<Table 1> Puncturing vectors

PI	Code Rate	$(v_{PI,0}, v_{PI,1}, \cdots, v_{PI,i}, \cdots, v_{PI,31})$
1	8/9	1100 1000 1000 1000 1000 1000 1000 1000
2	8/10	1100 1000 1000 1000 1100 1000 1000 1000
3	8/11	1100 1000 1100 1000 1100 1000 1000 1000
4	8/12	1100 1000 1100 1000 1100 1000 1100 1000
5	8/13	1100 1100 1100 1000 1100 1000 1100 1000
6	8/14	1100 1100 1100 1000 1100 1100 1100 1000
7	8/15	1100 1100 1100 1100 1100 1100 1100 1000
8	8/16	1100 1100 1100 1100 1100 1100 1100 1100
9	8/17	1110 1100 1100 1100 1100 1100 1100 1100
10	8/18	1110 1100 1100 1100 1110 1100 1100 1100
11	8/19	1110 1100 1110 1100 1110 1100 1100 1100
12	8/20	1110 1100 1110 1100 1110 1100 1110 1100
13	8/21	1110 1110 1110 1100 1110 1100 1110 1100
14	8/22	1110 1110 1110 1100 1110 1110 1110 1100
15	8/23	1110 1110 1110 1110 1110 1110 1110 1100
16	8/24	1110 1110 1110 1110 1110 1110 1110 1110
17	8/25	1111 1110 1110 1110 1110 1110 1110 1110
18	8/26	1111 1110 1110 1110 1111 1110 1110 1110
19	8/27	1111 1110 1111 1110 1111 1110 1110 1110
20	8/28	1111 1110 1111 1110 1111 1110 1111 1110
21	8/29	1111 1111 1111 1110 1111 1110 1111 1110
22	8/30	1111 1111 1111 1110 1111 1111 1111 1110
23	8/31	1111 1111 1111 1111 1111 1111 1111 1110
24	8/32	1111 1111 1111 1111 1111 1111 1111 1111

Protection profile contains the puncturing indices and the length of the blocks that the puncturing indices are applied. Table 2 and 3 show a protection profile applied in the FIC and MSC for transmission mode Ⅰ. For MSC we are only considering a video service transmitting at 544kbps.

<Table 2> Protection profile applied in the FIC

I	M	L	L_0	L_1	$V_{PI\,0}$	V_{PI1}
768	2304	24	21	3	16	15

<Table 3> Protection profile for the video bit rate 544kbits/s and protection level 3-A

I	M	L	L_0	L_1	$V_{PI\,0}$	V_{PI1}
13056	26112	408	405	3	8	7

The serial mother codeword generated from each I-bit vector is split into L consecutive blocks of 128 bits. The first L_0 blocks are punctured according to the puncturing index V_{PI0}. The remaining L_1 blocks are punctured according to the puncturing index V_{PI1}. This corresponds to a code rate of approximately 1/3. Finally, the last 24 bits of the serial mother codeword generated from the six tail bits are punctured. Therefore, the resulting punctured convolutional codeword of M bits is obtained. The same encoding procedure is applied to the four groups of I-bit vector. The encoding procedure in the MSC depends on the type of service carried, the net bit rate and the desired level of protection. The input vector of the mother convolutional encoder consists of I-bit vector, where I is a function of bit rate. Table 3 shows a protection profile for the video bit rate 544 kbits/s and protection level 3-A [5]. The serial mother codewords are split into 408 blocks of 128 bits. Using the puncturing vectors shown in Table III, we obtain the punctured convolutional codeword 26112 bits, which are transmitted in 9 OFDM symbols.

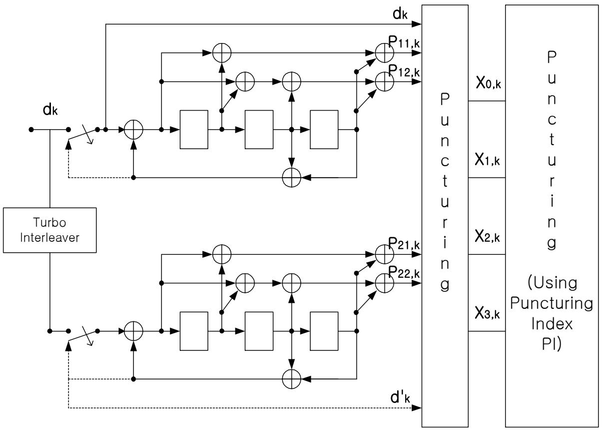
4. Turbo Coded T-DMB System

From the puncturing vectors defined in Table 1 we know that the first bit among the four coded bits is not punctured and always transmitted. Therefore, we can substitute the existing convolutional code with the turbo code because the information bits can be always transmitted as the systematic bits. For replacing a existing convolutional encoder by a turbo encoder, it is necessary not to modify the existing puncturing procedure and puncturing vectors for compatibility. First of all, to design a turbo encoder we must select a constraint length. The existing convolutional encoder having constraint length 7 needs six tail bits to flush the registers to zero state. Because the turbo encoder considered in this paper consists of the parallel concatenation of two constituent encoders, each constituent encoder with constraint length 4 is selected to separately flush the registers to zero state. Hence, a total of 6 tail bits which are equivalent to the standard convolutional encoder are needed to flush both of the constituent encoders. Next, we must choose a code rate for each constituent code. To obtain an overall code rate 1/4, each constituent code with code rate less than 1/2 is required. Therefore we choose a rate 1/3 code for each constituent code. It is known that maximizing the weight of output codewords corresponding to weight-2 data sequences, which weight dominates the performance characteristics, gives the best BER performance for a moderate SNR. A design for the best constituent codes for turbo codes by maximizing the effective free distance of the turbo code, in other words, the minimum output weight of codewords due to weight-2 input sequences, was reported in [6]. So, as a rate 1/3 constituent codes we use best rate 1/3 constituent codes with a maximum effective free distance. The best rate 1/3 constituent code is given by the code generator as follows

$$G=\left[1\ ,\ \frac{1+D+D^3}{1+D^2+D^3}\ ,\ \frac{1+D+D^2+D^3}{1+D^2+D^3}\right] \quad (3)$$

Fig. 4 shows the configuration of the designed turbo code encoder with a rate 1/3 constituent codes with constraint length of 4.

As a trellis termination, the switch allows to take input bits from register feedback. The designed turbo code results in an overall code rate 1/5. Therefore, the appropriate puncturing of the parity bits is required to obtain an overall code rate 1/4. This additional puncturing must be considered according to the puncturing vectors. Table 4 shows additional puncturing tables for each PI value. The puncturing tables for this additional puncturing are designed to transmit all the systematic bits from the first encoder and the same amount of parity bits from both encoders when the puncturing vectors are considered together.

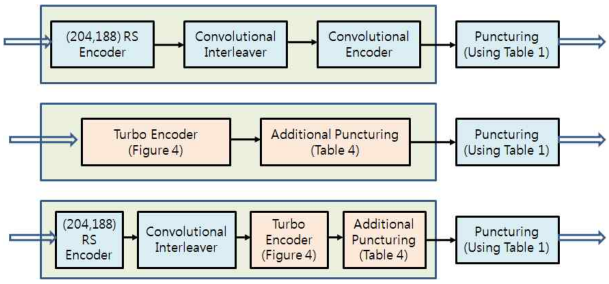


[Fig. 4] Configuration of the turbo encoder

<Table 4> Puncturing tables

PI	$(d_k, P_{11,k}, P_{21,k}, P_{12,k}, P_{22,k})$
1	11011 10111 10111 10111 10111 10111 10111 10111
2	11011 10111 10111 10111 10111 10111 10111 10111
3	11011 10111 10111 10111 11011 10111 10111 10111
4	11011 10111 10111 10111 11011 10111 10111 10111
5	11011 10111 11011 10111 10111 10111 11011 10111
6	11011 10111 11011 10111 10111 11011 10111 10111
7	11011 10111 11011 10111 11011 10111 11011 10111
8	11011 10111 11011 10111 11011 10111 11011 10111
9	11110 11011 10111 11011 10111 11011 10111 11011
10	11110 11011 10111 11011 11110 10111 11011 10111
11	11110 11011 11110 10111 11110 11011 10111 11011
12	11110 11011 11110 10111 11110 11011 11110 10111
13	11110 11101 11110 11011 11110 10111 11110 11011
14	11110 11101 11110 11011 11110 11101 11110 10111
15	11110 11101 11110 11101 11110 11101 11110 11011
16	11110 11101 11110 11101 11110 11101 11110 11101
17	11110 11110 11101 11110 11101 11110 11101 11110
18	11110 11110 11101 11110 11101 11101 11110 11101
19	11110 11110 11101 11101 11110 11110 11101 11110
20	11110 11110 11101 11101 11110 11110 11101 11101
21	11110 11101 11110 11110 11101 11101 11110 11110
22	11110 11101 11110 11110 11101 11110 11101 11101
23	11110 11101 11110 11101 11110 11101 11110 11110
24	11110 11101 11110 11101 11110 11101 11110 11101

Through the process of designing a turbo encoder we can come up with two types of turbo coded T-DMB system model without altering the puncturing procedure and puncturing vectors defined in the standard T-DMB system for compatibility. One(Type 1) can replace the existing RS code, convolutional interleaver and RCPC code by a turbo code and the other one(Type 2) can substitute the existing RCPC code by a turbo code. Two types of turbo coded system models are shown in Fig. 5.

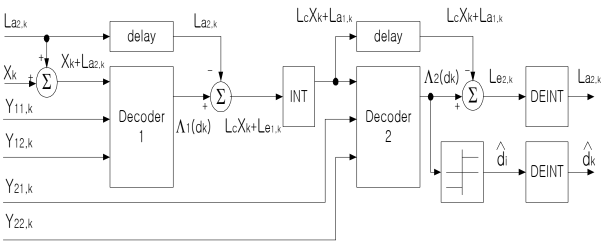


[Fig. 5] Turbo coded encoder

Fig. 6 gives a block diagram for a turbo code decoder. Punctured bits marked with “0” in the puncturing tables and puncturing vectors are depunctured with zeros. Soft-decision(likelihood) information for the systematic and parity bits from the first constituent code is sent to the first decoder. The decoder generates updated soft-decision likelihood values for the information bits that are passed to the second decoder as a priori information after reordering in accordance with the turbo interleaver. In addition, the second decoder accepts the updated likelihood information for the systematic bits and the soft-decision information from the channel for the parity bits from the second constituent encoder. The soft-decision output of the second decoder regarding updated likelihood information for the systematic bits is then fed back to the first decoder to repeat the process. The process can be iterated as many times as desired. As a decoding algorithm, the MAP algorithm is applied[7].

5. Simulation Results and Discussion

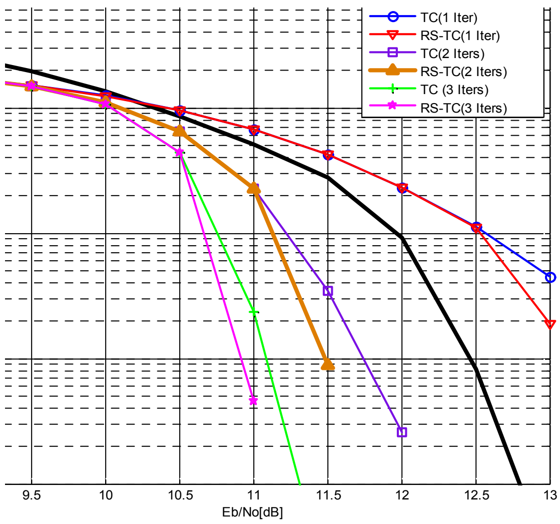
In this section, the performance of two types of turbo coded (TC) T-DMB system is evaluated by means of computer simulation under the Rayleigh fading channel, which is implemented by using channel parameters specified in European



[Fig. 6] Turbo code decoder

Telecommunication Standard Institute (ETSI) [8]. The average bit error rate(BER) versus E_b/N_0 performance between new TC systems and a standard (Reed Solomon and Convolutional code : RS-CC) system is compared in the MSC for T-DMB transmission mode Ⅰ. We assume that the protection profile and protection level for video transmission use table 3. The main parameters used for simulation are that the time interleaving depth is 384msec and the frequency interleaving depth is 1.536MHz. For the existed standard system, 8 levels soft decision is used. For the TC system, random interleaver is used.

Fig. 7 show the average BER curves after Viterbi or MAP decoding in the MSC. The result show that at a BER=10^{-3}, the turbo coded type 1 scheme which only uses turbo code offers an improvement of about 0.8dB and 1.4dB after 2 and 3 iterations over the existing scheme. And more than additional 0.2dB performance improvement is expected when the turbo coded type 2 scheme which uses RS code, convolutional interleaver and turbo code is considered. From this simulation result we are able to come to an conclusion that type 2 system is better than type 1 but the amount of performance improvement is small in spite of more amount of computation coming from RS code.



[Fig. 7] BER performance for 544kbps video transmission in Rayleigh channel.

6. Conclusions

The T-DMB system being able to transmit video service needs additional FEC blocks which consist of RS code and convolutional interleaver along with the existing RCPC code. In this paper we propose two types of turbo coded T-DMB system without altering the puncturing procedure and puncturing vectors defined in the standard T-DMB system for compatibility. One(Type 1) can replace the existing RS code, convolutional interleaver and RCPC code by a turbo code and the other one (Type 2) can substitute the existing RCPC code by a turbo code. Simulation results show that two new turbo coded systems are able to yield considerable performance gain after just 2 iterations. Type 2 system is better than type 1 but the amount of performance improvement is small.

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김 한 종(Kim, Han Jong)

- 1986년 2월 : 한양대학교 전자공학과(공학사)
- 1988년 8월 : 연세대학교 전자공학과(공학석사)
- 1994년 2월 : 연세대학교 전자공학과(공학박사)
- 1994년 9월 ~ 현재 : 한국기술교육대학교 전기전자통신공학부 교수
- 관심분야 : 방송시스템, 신호처리 및 마이크로 프로세서 응용
- E-Mail : hjkim@koreatech.ac.kr