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LDPC Coded Turbo Equalization for MIMO System

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Abstract —In this paper, MIMO (Multiple-Input-Multiple Output) system based on turbo equalization techniques which LDPC (Low Density Parity Check) codes were outer code and STTC (Space Time Trellis Code) were employed as an inner code are studied. LDPC decoder and STTC decoder are connected through the interleaving and de-interleaving that updates each other's information repeatedly. On the receiver side, in processing the turbo equalization with STTC decoder, in order to feed extrinsic information to STTC decoder, the extrinsic information of LDPC decoder must be two bit processing. However LDPC codes can't be applied to these system because LDPC decoder require just one bit processing. Therefore this paper proposes a turbo equalization model for LDPC codes able to apply MIMO systems combined with STTC codes. Through simulation results, we show that the performance of the proposed turbo equalization model is improved about 2.5 dB than that of turbo codes and about 10.5dB than that of conventional scheme.

Index Terms—Multiple-Input Multiple-Output, space time code, low density parity check code, layered space time code

I. INTRODUCTION

The broadband wireless communication systems are expected to provide users with high-speed wireless multimedia services. The rapidly growing demand for these services is driving the communication systems toward a higher data and performance improvement simultaneously. That’s why MIMO (Multiple-Input-Multiple-Output) technique and channel coding technique having a high performance are being studied until recent. MIMO communication systems employ multiple antennas at the transmitter and receiver sides. They can yield significantly increased data rates and improved link reliability without additional bandwidth [1]. In MIMO techniques, diversity techniques have been widely proposed to combat the adverse effects. Among them, the receiver antenna diversity has been shown to be successful in reducing the detrimental effects of the multipath channels. However, more can be gained by adding transmit diversity to further the antenna diversity gain. In [2] and [3], Tarokh et al. introduced STC (Space-time code) processing as a joint design of coding, modulation and transmitter diversity for flat Rayleigh fading environment. Such a STC system achieves the same diversity gain as the receiver diversity does. Recently, MIMO System used LST (Layered Space Time codes) systems combining STC with iterative codes [4]. Turbo equalization has been shown to improve the performance of decoders via iteration by concatenating the inner and outer codes with extrinsic information [5].

In this configuration, STTC (Space Time Trellis Code) codes are employed as an inner codes, and the outer codes considered are considered duo-binary turbo codes, which are recommended for DVB-RCS NG (Digital Video Broadcasting – Return Channel by Satellite Next Generation) [6], [7], and LDPC (Low Density Parity Check) codes, the standard codes for DVB-S2 (Digital Video Broadcasting – Satellite 2) and 802.11n [8]. The LDPC codes are not only less complex than the turbo codes, but also do not cause an error floor, due to their superior distance properties. Therefore, these codes can perform high-speed processing via full parallel processing. This high performance functionality can enable the configuration of a large encoder [9]-[13].

On the receiver side, as inner and outer decoder are connected through interleaving and de-interleaving, which allows the decoders to repeatedly updates each other’s information. Accordingly, the iterative configuration of the decoding unit should be considered first when connecting the STTC and outer codes. With the MIMO system, the input of the inner code is two bits. Likewise, two bits are generated at each antenna, modulated, and then transmitted as output. Therefore, when the decoding functions iteratively, the probability value for two bits should be emitted from the decoder of the inner code. With respect to the outer code, the output values should be sent as a probability value of two bits, which can be used as extrinsic information for the inner code to improve its performance via iteration. Although iteration between the inner and outer decoder is impossible, the iteration of each decoder may be possible. However, we cannot obtain the required performance by increasing the number of iterations of an individual decoder. Hence, pervious research has improved the performance of such decoder systems via a whole iteration by applying duo-binary turbo codes that obtain a probability of two bits. In contrast, the LDPC codes, which are superior to the turbo codes, cannot be applied in the MIMO systems, because their decoding process represents a LLR (Log-Likelihood Ratio) value of one bit. In order to resolve this problem, we propose a method that executes a whole iteration via separation or

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combination of bits, thereby connecting the STTC and LDPC codes.

In this study, the 32-state STTC method proposed by Blum [14], which is strong in both diversity and decoding, was employed as an inner code. With respect to outer codes, we employed, the LST model, which pairs the LDPC codes with outer codes. To wholly iterate the STTC and LDPC codes, we generated a probability value of one bit as the input value for the LDPC decoder by separating the probability value of two bits from the BCJR (Bahl, Cocke, Jelinek and Raviv) decoder [15].

We also reconfigured of the LLR value of one bit in the LDPC decoder into a LLR value of two bits via combination of symbols, the output of which was applied as the input value from the BCJR decoder.

In simulation results, the proposed method outperformed a conventional method that connects the turbo codes with the STTC by approximately 2.5 dB. Compared to a LST model conventional LDPC coded method based on hard decisions, the proposed method obtains coding gains of 10.5 dB.

II. LST MODEL BASED ON ITERATIVE CODES

Without loss of generality, we consider an $N \times M$ MIMO communication system equipped with N - transmit antennas and M - receive antennas. As shown in Fig. 1, MIMO system based on LST model which iterative codes were outer code and STTCs were employed as an inner code is depicted

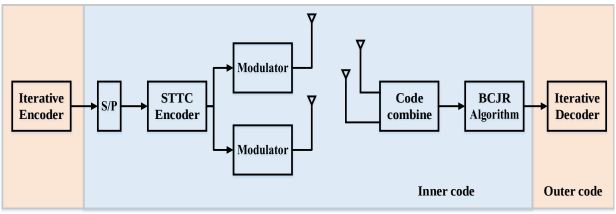


Fig. 1. STTC combined with iterative code.

The source bits to be transmitted bit-stream **D** is given by

$$\mathbf{D} = \{d_1, d_2, \ldots, d_K\}. \tag{1}$$

where K denotes a length of **D.** First, **D** is encoded by the (n, K) outer codes. Coded bit stream **C** is given by

$$\mathbf{C} = \{c_1, c_2, \ldots, c_n\}. \tag{2}$$

where n denotes a length of coded bits. Output of iterative coded bit stream, **C,** are input to STTC encoder as two bit wised parallel. The modulated signal from each transmit antennas is equal to the (3)

$$S_i = \{s_1, s_2, \ldots, s_l\}. \tag{3}$$

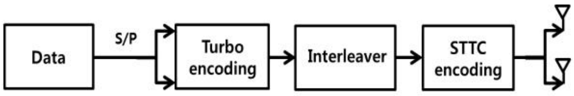
where S_i denotes transmitted signal from $i^{th}(i = 1, 2, \ldots, N)$ transmission antennas, l denotes the size of modulation output, and its sizes are different according to what kinds of modulation schemes are used. If QPSK (Quadrature Phase Shift Keying) modulation applied, l equals to $N/2$. The received signal at each antenna as follows

$$R_j = \{r_1, r_2, \ldots, r_l\}. \tag{4}$$

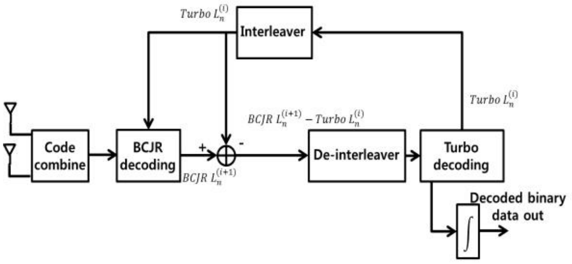
where R_j denotes received signal from $j^{th}(j = 1, 2, \ldots, M)$ receive antennas. The received signal R_j which has passed Rayleigh fading channels, has the diversity benefit, via code combine calculation which takes the average value by combining as much as M - receiving antennas. In this section, we discuss the MIMO system based on duo-binary turbo codes and LDPC codes.

A. *Conventional STTC Combined with Turbo Codes*

Fig. 2 shows that the LST model concatenate the STTC with turbo codes in a serial fashion [4]. In order to match the number of inputs and outputs from the BCJR decoder, we considered duo-binary turbo codes.



(a) Transmitter



(b) Receiver

Fig. 2. The LST combining space time codes with turbo codes.

32-state STTC method proposed by Blum [14] has a coding gain and diversity gain, STTC encoder output can be expressed as (5).

$$\begin{aligned} S_{n_1}(t) &= 2 \times \{c_2(t-\tau) \oplus c_1(t-2\tau) \oplus c_2(t-2\tau) \\ &\quad \oplus c_1(t-3\tau)\} + \{c_2(t-\tau) \oplus c_1(t-\tau)\} \\ S_{n_2}(t) &= 2 \times \{c_2(t) \oplus c_2(t-\tau) \oplus c_2(t-2\tau) \\ &\quad \oplus c_1(t-3\tau)\} + \{c_2(t-2\tau) \oplus c_1(t-\tau) \oplus c_1(t)\} \end{aligned} \tag{5}$$

where $S_n = \{s_{n1}, s_{n2}\}$ denotes the output value of the two transmitting antennas at time n in (3), and, $c_1(t), c_2(t)$ signifies the input bit of the STTC encoder at time t in (2). The expression $c(t-\tau)$ is a signal that is delayed in proportion to the τ of the i^{th} input signal. In this regard, (5) shows the four phase points $\{0,1,2,3\}$ with the corresponding QPSK symbols [3].

It was supposed that the simulation environment does not change as a Rayleigh fading channel having independent distribution during the symbol period of T.

It was also supposed that the receiver knows exactly the channel state information. The baseband equivalent signal received at m^{th} the receive antennas can be expressed in the discrete-time domain form as

$$R_m(t) = \sum_{i}^{N} h_{i,m}(t) s_i(t) + \eta(t) \tag{6}$$

where $t(t = 1, 2, \ldots, T)$ is the time index, $s_i(t)$ is the transmitted signal from i^{th} transmit antenna. $h_{i,m}(t)$ is the channel impulse response of the frequency-selective, $\eta(t)$ means an additive white Gaussian noise.

The received signal $R_m(t)$, compounds signals via code combination, in accordance with the number of receiving antenna. The resulting LLR value is output as much as the received bit stream size, via the BCJR decoder [15]. In each state, the probability values "00", "01", "10", and "11" are output. Therefore, the LLR value for S the input to the STTC in (5), can be obtained at the time as t, for each state m. The LLR values for four packages of two bits each i, j can be obtained using (7).

$$L\left(S_k^{ij}\right) = \min \left\{ \begin{matrix} \sum_m \lambda_k^{00}(m), \sum_m \lambda_k^{01}(m) \\ \sum_m \lambda_k^{10}(m), \sum_m \lambda_k^{11}(m) \end{matrix} \right\} (k = 1, 2, \cdots, K) \tag{7}$$

$\lambda_k^{00}(m), \lambda_k^{01}(m), \lambda_k^{10}(m)$, and $\lambda_k^{11}(m)$ denotes the LLR value for two input bits, i, j, each state, m. The decoding method of the BCJR as the STTC decoding algorithm, calculates the LLR value at each state in accordance with the input value of two bits. The estimated LLR value is then relocated to the address used prior to the interleaver of the transmitter, where it is finally input into the turbo decoder. Subsequently, the turbo decoder outputs the LLR value, which has the same form as that resulting from (7), via FSM (Forward State Metric) and BSM (Backward State Metric) processes. To do so, it decodes with a probability of two bits having received the LLR value of two bits. Therefore, after a predetermined number of iterations, the bit row is decoded as shown in (7).

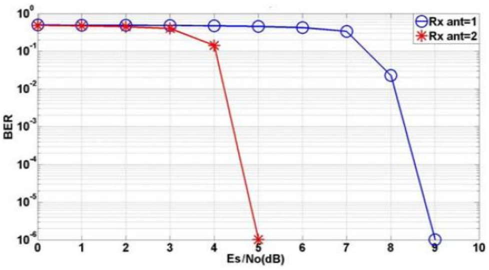


Fig. 3. BER performance of STTC combined with turbo codes.

When the transmitting antenna is fixed to two, and the receiving antenna is changed in the MIMO system, which is based on the LST model with connected turbo codes and STTC, the performance follows the model shown in Fig. 3. The turbo codes employed here are the size of transmitted bit, *K=984*, and the coding rate, *R=1/2*.

Thus, it could be reduced that a performance of approximately 4dB, with a BER 10^{-4}, improves when there are two receiving antennae, as opposed to one, due to the benefits of diversity and encoding of STTC as the number of antennae increases.

B. *Conventional STTC Combined with LDPC Codes*

Transmitting and receiving in a LST model by connecting existing LDPC code and STTC code, can enable a decoder system to use the LDPC code as the iteration code, as shown in Fig. 1.

At the STTC decoding stage, the BCJR decoder outputs the probability values of "00", "01", "10", and "11", with input or two bits. In contrast, the LDPC decoder has to decode using the received signal, which is sent to the decoder by one bit. Therefore, the soft decision output value for two bits from the BCJR decoder cannot be used as an input value for the LDPC decoder. Instead, the output value of one bit via hard decision should be input into the LDPC decoder, as shown in (8).

$$\mathit{if}\ L\left(S_k^{ij}\right) \equiv \lambda_k^{pq}(m) \quad \mathit{then} \quad i = p,\ j = q \tag{8}$$

The output of the LDPC decoder is the LLR value of a single bit, so it cannot be fed into the BCJR decoder. Consequently, the iterating the whole code for STTC and LDPC would be impossible. Even if iteration were possible, the performance of the decoder would not be improved through iterations.

III. PROPOSED LST MODEL COMBINING STTC WITH LDPC CODES

Although iterating between the BCJR decoder and LDPC decoders is impossible, the iteration of each decoder may possible. Importantly, we cannot obtain the required performance simply by increasing the number of iteration of an individual decoder. To overcome this problem, we propose a turbo equalization model for LDPC code that is able to apply MIMO system combined with STTC code, as shown in Fig. 4

Here, the symbol separation block and symbol combine block are added to the receiver, which will enable whole iteration. The symbol separation block is the output value of the BCJR decoder, which, itself, is the result of a soft decision of 1 bit. For this, the output LLR value of the BCJR decoder is reconfigured as a LLR value for 1 bit, as shown in (9) and (10).

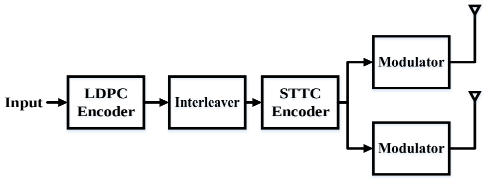
$$\begin{aligned} L\left(\hat{S}_k^{i0}\right) &= E\left(\sum_m \lambda_k^{i0}(m), \sum_m \lambda_k^{i1}(m)\right) \\ L\left(\hat{S}_k^{0j}\right) &= E\left(\sum_m \lambda_k^{0j}(m), \sum_m \lambda_k^{1j}(m)\right) (k = 1, 2, \cdots, K) \end{aligned} \tag{9}$$

$$\begin{aligned} L\left(\hat{R}_{m=2k-1}\right) &= L\left(\hat{S}_k^{00}\right) - L\left(\hat{S}_k^{10}\right) \\ L\left(\hat{R}_{m=2k}\right) &= L\left(\hat{S}_k^{00}\right) - L\left(\hat{S}_k^{01}\right) (k=1,2,\cdots,K) \end{aligned} \tag{10}$$

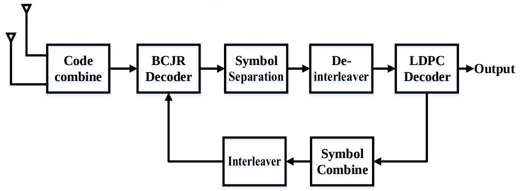
As shown in (9), $L(\hat{S}_k^{i0})$ denotes the probability value of the first bit of the two bits from the BCJR decoder's LLR values. A value of $i=0$ indicates a probability of '0'. When $i=1$, the probability is read as '1'. The relation $L(\hat{S}_k^{0j})$ is used to calculate the probability value of the second bit. When $i=0$ or $j=1$, the probability of the second bit is '0' and '1', respectively. The two bits of LLR value are calculated by dividing them into the LLR value for the first bit and that for the second bit, respectively. The LLR value for each bit can be calculated using (10).

As shown in (10), $L(\hat{R}_m)$ reformulates the LLR value for each bit by subtracting the probability value of '1' from the probability value of '0'. Thus, $L(\hat{R}_m)$ is reformulated at the BCJR decoder using (10), and is then relocated through via the de-interleaver to the address before the interleaver at the receiving end. Finally, it enters the LDPC decoder, which then proceeds with decoding.

However, this method cannot execute the whole iteration. Nonetheless, it largely improves the capacity in comparison with the existing method, which connects the STTC with LDPC code. The LLR value, which is estimated via the LDPC decoder, signifies a probability of '0' and '1' for each bit; however, it cannot be presented as the probability of two bits. Therefore, a whole iteration is not possible. In order to address this problem, we apply a symbol combine in the receiver structure shown in Fig. 4.



(a) Transmitter



(b) Receiver

Fig. 4. Proposed LST combining STTC with LDPC codes.

The symbol combine integrates the bit of the LLR value $L(u_k)$, which has been estimated with the LDPC decoder, such as (11) and (12).

$$\begin{aligned} L\left(B_k^{00}\right) &= L(u_{2k-1}) - \left|L(u_{2k-1})\right| \\ L\left(B_k^{01}\right) &= \left|L(u_{2k-1})\right| \quad \left(L(u_{2k-1}) < 0,\ k=1,2,\cdots,K\right) \end{aligned} \tag{11}$$

$$\begin{aligned} L\left(B_k^{10}\right) &= L(u_{2k}) \\ L\left(B_k^{11}\right) &= L(u_{2k}) - \left|L(u_{2k})\right| \left(L(u_{2k}) \geq 0,\ k=1,2,\cdots,K\right) \end{aligned} \tag{12}$$

$L(u_k)$ denotes the output LLR value of the LDPC decoder for the input value u_k at time k. The terms B_k^{00}, B_k^{01}, B_k^{10}, and B_k^{11} indicate the combined bits used to express the output LLR value of one bit from the LDPC at each state, as two bit probabilities of '00', '01', '10', '11'.

The signal, the bit of which is combined via (11) and (12), updates the probability of these two bits in the BCJR decoder using an interleaver, as shown in (13).

$$\begin{aligned} L\left(\hat{u}_k^{00}\right) &= L\left(B_k^{00}\right) + L\left(B_k^{10}\right) \\ L\left(\hat{u}_k^{01}\right) &= L\left(B_k^{00}\right) + L\left(B_k^{11}\right) \\ L\left(\hat{u}_k^{10}\right) &= L\left(B_k^{01}\right) + L\left(B_k^{10}\right) \\ L\left(\hat{u}_k^{11}\right) &= L\left(B_k^{01}\right) + L\left(B_k^{11}\right) \quad (k=1,2,\cdots,K) \end{aligned} \tag{13}$$

This proposed method enables a whole iteration between STTC decoder and LDPC decoder, thereby improving the overall performance of the decoder system.

IV. SIMULATION RESULTS

The STTC encoder used in our simulation analyzed the performance of a 32-state STTC with two receiving antennae, when the number of receiving antenna was one or two. The LDPC encoder assumed the standard size of a transmitted bit to be *K=32400*, with a coding rate of *R=1/2* and QPSK modulation scheme.

We assumed that the simulation environment did not change in relation to a Rayleigh fading channel with independent distribution during the symbol period, T. We also assumed that the receiver knew the exact channel state information.

Fig. 5 shows the BER performance, one parameter of which expressed the BER performance in relation to the number of receiving antennae when the existing STTC and LDPC codes are connected via (5). The other diagram displays the BER performance based on the value of the result of a soft decision from the BCJR decoder as the input for the LDPC decoder using (9) and (10).

The result of the simulation that connected the existing STTC and LDPC codes showed that error floor occurred when the number of the receiving antennae was one. The system's performance improved by approximately 13dB, at a BER of 10^{-4}, when there were two receiving antennae. As a result, we confirmed that the performance of the LDPC encoder was improved by using the soft decision from the output of the BCJR decoder. However, the whole iteration between the BCJR and LDPC decoder was enabled. To overcome this problem, we simulated the proposed method via (12) and (13)

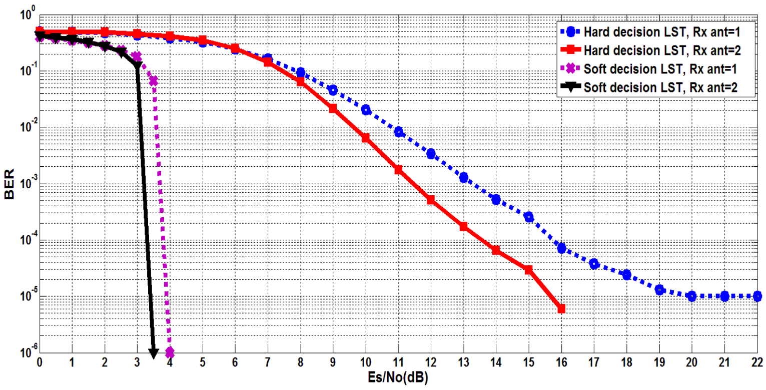


Fig. 5. BER comparison between conventional and soft output based on LST model.

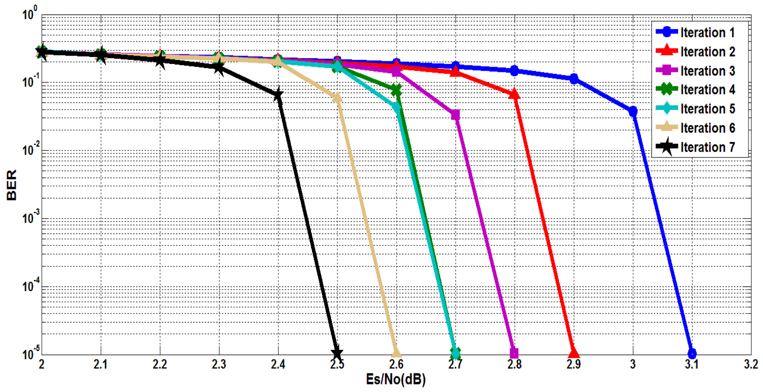


Fig. 6. The proposed method for BER performance of increasing iteration.

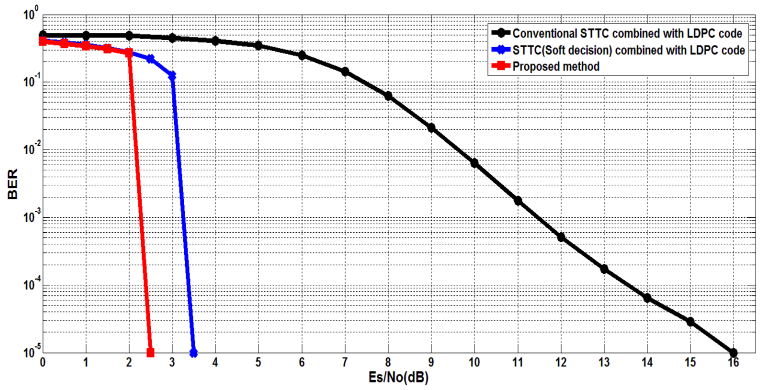


Fig. 7. BER comparison between conventional and proposed method.

According to Fig. 6, when the whole iteration between the BCJR and LDPC decoder was executed seven times using the proposed method, the performance of the decoding system improved by 0.6 dB in comparison with that from one iteration, using a BER of 10^{-4}.

Fig. 7 shows the BER performance. The black line shows the BER performance using a conventional method in which a LST model based on STTC used a hard decision value and the LDPC codes. The blue line shows the BER performance using a LST model based on STTC with a soft decision value and LDPC code. The red line shows the proposed BER performance using a turbo equalization model for LDPC code that is able to apply a MIMO system combined with STTC code.

According to Fig. 7, we confirmed that the performance of our proposed turbo equalization model improved to approximately 2.5 dB more than that of turbo codes shown in Fig.3, and approximately 10.5dB more than that of conventional LDPC code, using a BER of 10^{-4}.

V. CONCLUSIONS

In this paper, MIMO system based on turbo equalization techniques with LDPC codes were outer code and STTC were employed as an inner code are studied. In conventional method, the iteration of the whole codes of STTC and LDPC is impossible, but only the iteration of each code in the decoder is possible. As a result the performance is degraded. To overcome this problem, we proposed the enable whole iteration between STTC and LDPC codes. And it was confirmed the simulation results.

Comparing the results of simulation with two receiving antennas, using a BER of 10^{-4}, we confirmed that the performance of our proposed method, which connected the turbo code with STTC, was better than a conventional LST model based on hard decisions by approximately 9 dB. In contrast, the performance of the decoder system improved to approximately 2.5 dB more than that of the conventional model, which connected the turbo code with STTC.

In comparison with the conventional LST model based on hard decisions, and which connects the existing LDPC code with STTC, the proposed method improved the performance of the decoder system by approximately 10.5dB. In this regard, we find that the structure proposed in this study is appropriate for the recently wireless developed communication system.

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