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위성통신시스템에 대한 효율적인 무율부호 적용

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Efficient Application of Rateless Codes for Satellite Communication Systems

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요 약

본 논문에서는 무율부호를 이용하여 위성시스템에서의 강우 감쇠를 극복할 수 있는 효율적인 기법을 제안한다. 제안된 기법에서는 디지털위성방송표준의 하나인 DVB-S2(X)에 정의되어 있는 LDPC 부호를 활용하여 무율부호를 설계한다. LDPC 부호어를 무율부호의 정보어로 간주하고, 무율부호의 부호기는 강우감쇠를 극복하기 위하여 두 가지 방법으로 패리티를 생성한다. 첫 번째 방법은 복호가 성공할 때까지 정해진 길이의 패리티를 계속 재전송하는 방법이고, 두 번째 방법은 예측된 페이딩 값에 적절한 패리티를 길이를 한번만 재전송하는 것이다. Ka 대역 위성강우감쇠 모델을 적용하여 시뮬레이션을 수행하고, 그 결과를 제시하여 본 논문에서 제시한 기법이 효과적으로 강우감쇠를 극복하는데 활용될 수 있음을 보인다.

Key Words : rateless codes, satellite systems, rain fading, satellite broadcasting services, LDPC codes

ABSTRACT

This paper proposes efficient techniques to countermeasure rain fading in the satellite systems by utilizing rateless codes. In the proposed scheme, rateless codes are designed for the LDPC codes defined in the DVB-S2(X) system which is a technical standard for digital satellite broadcasting services. By taking the codewords of the LDPC code as the systematic parts, the encoder of the rateless code generates their parities in two different ways in order to compensate rain fading. The first one is to transmit a given length of parities at every retransmission until the decoding is succeeded, while the second one is to transmit adaptive length of parity which is suitable for the predicted fading value and retransmission is made only once. Simulations are performed by using a satellite rain-fading channel model in Ka frequency band, and the results demonstrates that the proposed scheme can be effectively utilized to compensate rain fading.

Ⅰ. Introduction

DVB-S2, known as the second-generation standard for satellite video broadcasting was developed in the digital video broadcasting (DVB) project[1]. Low density parity check (LDPC) codes are forward error correction (FEC) coding schemes specified in the DVB-S2 system, and they are

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known to provide a performance close to the Shannon's limit due to a soft iterative decoder at the receiver. The DVB-S2 defines two kinds of FEC frames which are the normal frame with a length of 64800 bits and the short frame with a length of 16200 bits. It provides eleven different code rates for the normal frame and ten rates for the short frame[2]. Recently, the DVB-S2 extensions (DVB-S2X) specified additional code rates for LDPC codes, as extensions to DVB-S2[3].

Satellite systems need to have adaptive coding and modulation (ACM) scheme to suitably counteract severe rain fading, especially if they are operated in the frequency range over 10 GHz. Multiple code rates of the LDPC codes in combination with M-ary amplitude and phase shift keying (APSK) modulation scheme can be utilized in the ACM scheme in order to counteract time-varying channel conditions, as defined in the DVB-S2 and DVB-S2X system[1][3]. Nevertheless, LDPC codes do not have their own rate compatibilities, and thus they can hardly applied to incremental redundancy applications, such as hybrid automatic repeat request (HARQ)[4].

Luby transform (LT) codes were introduced as the first rateless codes[5], and previous studies proposed to use the LT codes as an effective retransmission means to counteract channel fading, by using its unlimited parity generation capability. Specifically, the previous studies proposed a HARQ scheme with rateless LDPC codes[4], and provided an application example for satellite systems[6].

Extending the idea, this paper proposes two different methods of utilizing rateless codes to compensate rain fading in satellite system. In the transmitter, the encoder for the rateless code takes the codewords of the LDPC code as the systematic parts, and generates their parities. In the first method, whenever the decoding fails for the target information, a given length of parity is generated and transmitted until the decoding is succeeded, and thus multiple retranmissions can be made in a deep fading condition. On the other hand, an adaptive length of parity which is suitable for the predicted fading value is generated and transmitted again, and this retransmission of parity is made only one time.

This paper is organized as follows. After this introduction, Section II describes the system model which provides satellite broadcasting services with the proposed scheme under a rain fading channel. Section III demonstrates the simulation results over a rain fading channel, and finally conclusions are drawn in Section IV.

Ⅱ. Rateless codes for satellite systems

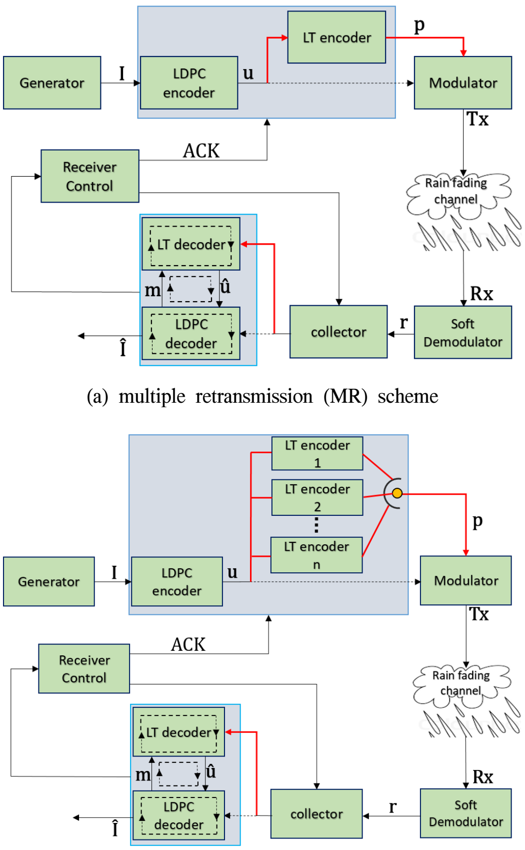
2.1 System model and operational principle

Satellite systems utilizes an ACM scheme to suitably counteract severe rain fading. Especially if they are operated in the frequency range over 10 GHz, then utilization of the ACM scheme is almost mandatory. The system with ACM requires to investigate the history of the received signal quality and to predict it for the optimum allocation of the resources.

Even though data transmission with ACM can be effectively countermeasure the rain fading, prediction and allocation error may cause performance degradation. In this case, utilization of rateless codes can be an effective solution. Having the LDPC codes used in the ACM operation as they are, we can generate additional parities by treating the codewords of the LDPC codes as the systematic parts of the LT codes. Figure 1 shows operational principles of the proposed system in two different ways.

The system shown in Fig. 1 (a) allows multiple retransmissions without having any predictions on the signal quality. We refer to this method in this paper as the multiple retransmission (MR) scheme. At the initial transmission, the information, $\mathbf{I}$, of length K is encoded to systematic DVB-S2 LDPC codeword $\mathbf{u}$, of lengthg k, at the transmitter. After that $\mathbf{u}$ is modulated and transmitted through the channel.

At the receiver, $\mathbf{r}$ is demodulated by estimating soft information. Then the LDPC decoder starts decoding using $\mathbf{r}$ as the decoder input. As a result of iterative estimation, a soft output $\mathbf{m}$ is produced. The LDPC decoder finishes decoding if the



(a) multiple retransmission (MR) scheme

(b) adaptive parity length (APL) scheme

그림 1. 위성 강우 채널에서의 무율 부호 활용
Fig. 1. Utilization of rateless codes over a satellite rain fading channel

parity-check equation is satisfied, and the acknowledgement (ACK) message will be delivered to the transmitter in order to initiate transmission of the next information block.

On the other hand, if the parity check equation is not satisfied, then Non-Acknowledgement (NACK) message is delivered to the transmitter for retransmission of parities. The LT encoder produces a given length of parity-check bits, **p** by using **u** as an input, and **p** is modulated and sent to the receiver. Then LT decoder adds soft information on **p** to the previously estimated soft information on **u**, and updates it to û, then û is provided to the LDPC decoder.

In this manner, the LDPC and LT decoders work jointly by exchanging their soft information iteratively. If the decoded result from the LDPC decoder satisfies the parity check equation, then the acknowledgement (ACK) message will be delivered to the transmitter in order to initiate transmission of the next information block. Otherwise, the NACK message is delivered again to the transmitter for retransmission of another parity with the same length. This process is repeated until the parity check equation is satisfied or the maximum number of allowed retransmissions.

Second, referring to (b) of Fig. 1, initial transmission process is exactly the same as the method in (a) of Fig. 1. When the parity check equation is not satisfied, with the delivered NACK message, the transmitter allows only one retransmission. In this method, the length of parity is not static, but it is adaptive to the channel condition. In other words, a longer length of parity is transmitted if the predicted channel condition becomes worse. In this paper, we refer to this method as the adaptive parity length (APL) scheme.

2.2 Joint iterative decoding for performance enhancement

Figure 2 shows a Tanner graph which can be efficiently used for joint decoding of LDPC and LT codes. Because both of the codes are based on the Tanner graph by sharing the bit nodes, both codes can be decoded with the same decoding algorithm, and soft information can be easily exchanged

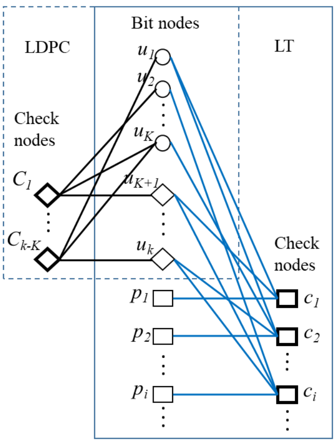


그림 2. 결합반복복호를 위하여 변형된 태너 그래프
Fig. 2. Modified Tanner graph for joint iterative decoding

through the bit nodes[7].

Before the decoding, the soft input information is first estimated from the log-likelihood rario (LLR) of the received information vector **r.** Afterwards, The joint iterative decoder first activates iterative decoding for LT codes. After initial soft decoding of LT codes, LT decoding and LDPC decoding can be performed in parallel by exchanging the soft output values through the shared bit nodes.

Ⅲ. Simulation Results

3.1 Simulation Model

We simulated the performance of the proposed methods over a synthesized satellite rain fading channel at Ka frequency band[8]. By considering the round trip delay of geo-stationary orbit satellite system, the fading value is generated with an interval of 1 second, and it is assumed that every retransmission is made with the same time interval. We limit the minimum fading depth to －24 dB for simplifying simulation.

The short frame sized DVB-S2 LDPC code with a rate of ½ is utilized as a systematic part of the rateless code. For the rateless codes, we utilized LT codes with robust soliton distribution[5]. In the MR method of Fig. 1 (a), a fixed length of parity corresponds to 20% of the length of the LDPC codeword is used at every retransmission.

The maximum number of retransmissions is set to 11. On the other hand, in the APL method of Fig. 1 (b), the length of the parity used in the retransmission is adaptive, depending on the channel condition, and the retransmssion is made only once. The maximum length of parity length is set to the maximum value of R^{-1} to be 3, where R is the code rate of the rateless code. By this way, the maximum codeword length of the rateless codes of the both MR and APL methods are the same. For the joint iterative decoding at the receiver, we set the maximum number of iterations for LT decoding, LDPC decoding, and joint iterative decoding to 20, 40, and 3, respectively.

3.2 Performance comparison with simulation results

Performances of the proposed schemes were simulated by setting the signal to noise ratio (SNR) value in terms of symbol energy to noise spectral density ratio (E_s/N_0) to 10 and 18 dB, respectively. Table 1 shows performance comparison of the both MR and APL schemes compared with the conventional LDPC coding scheme. As shown in Table 1, the bit error rate (BER) performances of the proposed methods are highly enhanced, especially with the MR scheme at the expense of retransmission delays.

Figure 3 shows the probability density function (PDF) of the number of retransmissions, n_r in the MR scheme. Because most of the codewords could be decoded successfully with n_r of 1, the PDF, $f_{N_r}(n_r)$ shown in Fig. 3 is represented when $n_r > 1$. In Figures 3 and 4, $\overline{X}$ denotes the statistical average of random variable, X. The probability of having larger n_r is reduced as the SNR value is

표 1. 제안된 방식에 대한 BER 성능 비교
Table 1. BER Performance comparison of the proposed schemes

scheme \ SNR (dB)	10	18
Conventional LDPC	5.44×10^{-3}	7.87×10^{-4}
MR	3.76×10^{-4}	6.21×10^{-6}
APL	2.05×10^{-3}	7.32×10^{-5}

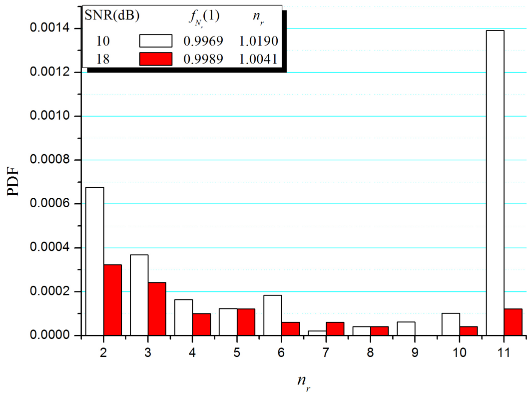


그림 3. MR 방식에서 n_r에 대한 PDF
Fig. 3. PDF of n_r in the MR scheme

increased.

On the other hand, Figure 4 shows the PDF of R^{-1} of the rateless codes, $f_{R^{-1}}(R^{-1})$ used in APL method. Similar to the MR scheme, most of the codewords could be decoded when R^{-1}=1, and thus the PDF, $f_{R^{-1}}(R^{-1})$ is shown for R^{-1} > 1. With higher SNR, the probability of larger R^{-1} is decreased.

Table 2 compares the average effective code rate, r_e of the proposed schemes. The conventional LDPC coding scheme in Table 1 utilized rate 1/2 code, and thus it has r_e of 0.5 regardless of SNR values. On the other hand, with the APL scheme, the average effective code rate can be expressed as $r_e = 0.5\left(\overline{R^{-1}}\right)^{-1}$. With the MR scheme, $r_e = 0.5\left[1+0.2\left(\overline{n_r}-1\right)\right]^{-1}$. From the results investigated in Table 1 and 2, the MR methods produces better performances in terms of not only BER but also r_e. We note, however, the MR method should sacrifice a longer delay due to multiple retransmissions.

표 2. 평균 유효 부호화율, r_e에 의한 제안된 방식의 처리율 비교
Table 2. Throughput comparison of the proposed schemes, in terms of average effective code rate, r_e

scheme \ SNR (dB)	10	18
Conventional LDPC	0.5	0.5
MR ($0.5\left[1+0.2\left(\overline{n_r}-1\right)\right]^{-1}$)	0.4981	0.4909
APL ($0.5\left(\overline{R^{-1}}\right)^{-1}$)	0.4996	0.4985

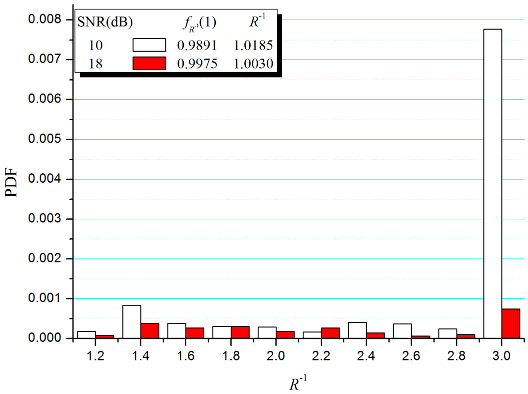


그림 4. APL 방식에서 R^{-1}에 대한 PDF
Fig. 4. PDF of R^{-1} in the APL scheme

Ⅳ. Conclusion

We proposed two methods of utilizing rateless codes in order to compensate rain fading in satellite systems. Both methods use conventional LDPC codes defined in the DVB-S2 system as the systematic part of the rateless code. From the simulation results demonstrated in this paper, the proposed MR and APL schemes can be effectively used to improve the service quality of satellite services. The MR scheme showed a slightly better performance than the APL scheme at the expense of additional delay. In the future, we will investigate a method to combine advantages of the both proposed methods in order to reduce the numbers of retransmissions and enhance the performance.

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