DVB-RCS 시스템에서 터보 부호의 오류성능 목표 분석

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Analysis on the error performance objective for turbo codes in the DVB-RCS system

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요 약

디지털 위성 통신 시스템은 다양한 서비스를 제공하기 위하여 지상망과 통합되어 사용되는 경우가 많다. 이 경우에 위성 통신 시스템은 지상망에서 정의한 성능 목표를 만족시켜야 한다. ITU-R 권고서 S.1062 에서는 15 GHz 이하의 디지털 위성 통신 시스템의 오류 성능 목표를 명시하고 있다. 권고서에서는 오류 버스트 내의 평균 오류의 개수를 α 로 정의하고 비트 오류 확률 나누기 α 를 오류 성능 목표로 제시하고 있다. 본 논문에서는 이러한 오류 성능 목표를 분석하는데 있어서 오류 버스트 내의 평균 오류 개수인 α 값을 이론적으로 구하는 방법을 제시한다. 이를 토대로 길쌈 부호의 이론 값 및 이에 바탕을 두고 있는 DVB-RCS 터보부호의 α값에 대한 이론 값을 구하고 시뮬레이션 값과 비교하여 α 의 이론적인 계산식을 증명해 보일 것이다.

ABSTRACT

Digital satellite communication systems are usually integrated with terrestrial systems to provide various services. In these cases, they should satisfy the performance objectives defined by the terrestrial systems. Recommendation ITU-R S.1062 specifies the error performance objectives of digital satellite communication systems operating below 15 GHz. The error performance are given in terms of bit error probability divided by the number of the average bit errors in the burst (α). This paper presents a theoretical method to estimate α that is a very important parameter in the satellite communication systems to analyze the error performance objectives. We show performance estimation results of DVB-RCS turbo code using the presented method, and verify them by comparing to the simulation results.

Key Words : Error Correction Codes, Turbo codes, DVB-RCS, ITU-R Recommendation, error performance

Ⅰ. Introduction

Satellite services can be provided in various forms by integrating terrestrial systems. Services of international telephone and broadcasting can be those examples. In the case of integration with the terrestrial components, they should satisfy the performance objectives defined by the terrestrial

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systems.

International Telecommunications Union - Telecommunications (ITU-T) Recommendation G.826 defined error performance objectives of satellite hop in the international portions[1]. Many international communication services use satellite systems because of its advantages of wide coverage area. In order to reflect the requirements defined by G.826, ITU-R (Radiocommunications) Recommendation S.1062 was developed to specify the error performance objectives in digital satellite communication systems, and it was called as a design mask[2].

The design mask in ITU-R Recommendation S.1062 is specified by the bit error rate (BER) divided by the average number of errors per burst. Modern digital satellite systems must adopt forward error correction (FEC) scheme in order to compensate various channel losses, and thus the errors tend to occur in clusters at the output of the decoder. The average number of errors per burst which is defined by α is very important to estimate the performance of a digital satellite system, and it is function of a specific FEC scheme employed in the system. In addition, the α value is dependent on the channel error rates, that is BER. The BER is a function of the signal to noise ratio, and the modulation scheme employed in the system.

For a digital satellite system designer, it is necessary to estimate α values for candidate FEC schemes by the Recommendation. This situation calls a compact way to estimate α values in addition to the BER. In this paper, we present a theoretical method to estimate α values. We estimate α values by using the weight distribution of the code interested, and show a lower bound which can be a close approximation at the specified design mask.

After this introduction, we briefly show the design mask given in ITU-R Recommendation S.1062 in section 2. Section 3 is devoted to derive theoretical value of α and its lower bound, and we also apply them to DVB-RCS turbo codes. We compare the estimation results to the simulation results and verify them. Finally, Section 4 draws the conclusion.

Ⅱ. Allowable error performance for a digital satellite system

ITU-R Recommendation S.1062 recommends that future and, wherever possible, existing satellite links within the FSS should be designed to at least meet the specifications for a satellite hop in the international portion in ITU-T Recommendation G.826, the BER divided by the average number of errors per burst (BER/α) should not exceed during the total time the design masks defined by the values given in Table 1[2]. Upon the requirements defined in Table 1, a satellite system designer should estimate BER and α values for their candidate schemes.

It is well known that errors on satellite links employing FEC and scrambler schemes tend to occur in clusters. The appearance of the clusters, which can also be called error events, is random following a Poisson distribution[2]. The resulting block error rate is the same as if it were caused by randomly (Poisson distributed) occurring bit errors with a bit error ratio BER/α. α is the average number of errored bits within a cluster, and α also represents the ratio between the BER and error-event ratio. For example, in a random binary error channel without FEC and scrambler α is considered to be one. With higher order modulation schemes, however, α may be larger than one.

Statistical properties of the clusters of errors are dependent on the FEC scheme used. In a given FEC scheme, theoretical values of α can be estimated using the weight distribution of the FEC scheme. In the next section, we show the theoretical derivation of α.

Table 1. The design mask of a digital satellite system

Bit rate (Mbit/s)	Percentage of total time	BER/α
0.064	0.2	1.0×10^{-4}
	10.0	1.0×10^{-8}
1.5	0.2	7×10^{-7}
	2.0	3×10^{-8}
	10.0	5×10^{-8}
2.0	0.2	7×10^{-6}
	2.0	2×10^{-8}
	10.0	2×10^{-9}
6.0	0.2	8×10^{-7}
	2.0	1×10^{-8}
	10.0	1×10^{-9}
51.0	0.2	4×10^{-7}
	2.0	2×10^{-9}
	10.0	2×10^{-10}
155	0.2	1×10^{-7}
	2.0	1×10^{-9}
	10.0	1×10^{-10}

Ⅲ. Derivation of the average number of errors per burst

Given an (n, k) systematic block code C, its well-known weight enumeration function (WEF) is

$$B^C(H) \doteq \sum_{i=0}^{n} B_i H^i, \quad (1)$$

where B_i is the (integer) number of codewords with Hamming weight (number of ones) i and H is a dummy variable[3]. The WEF of a code can be used to compute the exact expression of the probability of undetected errors and an upper bound to the word error probability.

The input-redundancy weight enumerating function (IRWEF) of the code can be defined as

$$A^C(W,Z) \doteq \sum_{w,j} A_{w,j} W^W Z^j, \quad (2)$$

where $A_{w,j}$ denotes the (integer) number of codewords generated by an input information word of Hamming weight w whose parity check bits have Hamming weight j, so that the overall Hamming weight is $w+j$. the IRWEF show the separate contributions of the information and of the parity check bits to the total Hamming weight of the codewords, and thus provides additional information on the (Hamming) weight profile of the code.

By using the above expression, the bit error probability, P_b, can be upper-bounded by

$$P_b \leq \sum_{n=d_{\min}}^{n} D_m P(R''_m | C_0), \quad (3)$$

where d_{min} is the minimum distance of the code, $P(R''_m|C_0)$ is the probability for the decoder selecting the codeword of weight m provided the transmitted codeword is all-zero codeword, and

$$D_m = \sum_{j+w=m} \frac{w}{k} A_{w,j} \quad (4)$$

Therefore, the average number of bits in a cluster α will be the mean value of w provided that we have decoding error, and leading to

$$\overline{w} = \sum_{m=d_{\min}}^{\infty} \sum_{m=w+j} w A_{w,j} P_m \quad (5)$$

where P_m is the probability of error events with m errors in all error events, that is $P(R''_m|C_0)$. Because P_m decreases rapidly with m, especially in low BER values, the lower bound of α can be approximated by

$$\alpha \geq \frac{\sum_{d_{\min}=w+j} w A_{w,j}}{\sum_{d_{\min}=w+j} A_{w,j}}, \quad (6)$$

and this is well approximated in low BER values.

Ⅳ. Application to the DVB-RCS turbo codes

4.1 DVB-RCS turbo codes

DVB-RCS (Digital Video Broadcasting - Return Channel via Satellite) is a standard for two-way communication from fixed terminal on the ground to satellite using a geostationary orbit satellite in the digital broadcasting system[4]. Figure 1 shows encoder diagram of the turbo codes specified in the DVB-RCS. It uses double binary circular recursive systematic convolutional (CRSC) code. "Double binary" means that a couple of two bits are fed into the encoder at the same time. In the turbo encoder two recursive systematic convolutional codes are concatenated in parallel. Similar to the convolutional codes defined in the DVB-RCS standard, rate compatible turbo codes are also used. Seven code rates are defined for the turbo codes with rate of 1/3, 2/5, 1/2, 2/3, 3/4, 4/5, and 6/7. This is achieved through selectively deleting the parity bits (puncturing).

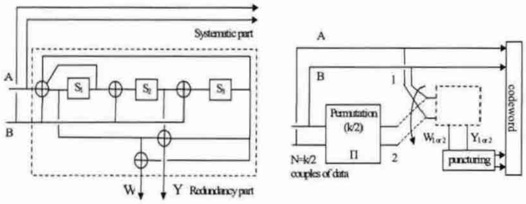

Fig 1. Encoder structure of the DVB-RCS turbo code

4.2 Estimation of α for DVB-RCS turbo codes

Because DVB-RCS turbo codes are based on convolutional codes, we can apply a similar approach that is used for convolutional codes. For known convolutional codes, various studies identified their weight distributions in terms of a_d, the number of codewords of distance d, and c_d, the sum of bit errors (the information error weight) for codewords of distance d[5-7]. With the same lower bound approximation derived in the previous section, the lower bound of α for the convolutional codes can be approximated to

$$\alpha \geq \frac{c_{d_f}}{a_{d_f}}, \tag{7}$$

where d_f is the free distance of the code.

Reference[8] showed weight distribution of DVB-RCS turbo codes, and Table 2 shows a part of them. Table 3 shows corresponding estimated α values. Figure 2 compares to the simulated α values for the packet size of 53 bytes. Because the turbo codes use an iterative decoding algorithm, α values and BER depend on the decoding algorithm and the number of iterations. In the simulation, a max-log MAP decoding algorithm was used and α values were estimated at iterations of 6 and 15. Because the theoretical values estimated in Table 3 are lower bound values, they are smaller than the simulated α values in Figure 2.

Table 2. Weight distribution of turbo codes(d_f/a_d/c_d)

packet size (bytes)	R=1/3	R=1/2	R=3/4	R=6/7
53	31/106/954	18/159/954	7/10/50	4/9/27
188	33/3476/3384	19/376/3384	9/27/171	6/199/826

Table 3. Lower bound of α values for turbo codes

packet size (bytes)	R=1/3	R=1/2	R=3/4	R=6/7
53	9.00	6.00	5.00	3.00
188	9.00	9.00	6.33	4.15

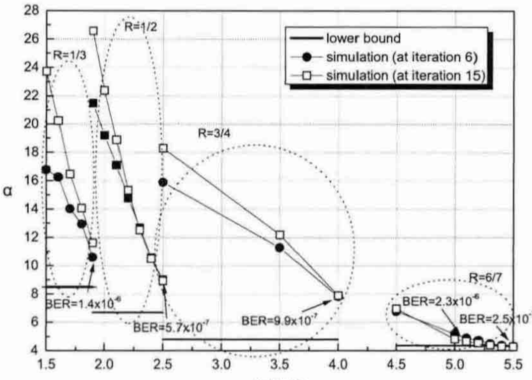

Fig 2. Comparison of α for turbo codes

Ⅴ. Conclusion

In this paper, we presented a theoretical formula to estimate error performance parameter for digital satellite systems. In addition, we provide a compact way to estimate lower bound which can be used in normal operating range of the system. We estimated the theoretical value for turbo codes in the DVB-RCS system. The estimation results of the turbo codes investigated in this paper reveal that the theoretical estimation results using the presented method are well agreed to the simulation results, and thus it can be used to estimate the error performance very easily. Therefore, the method presented in this paper can be used to estimate the error performance of various FEC schemes, and plays important role in digital system design.

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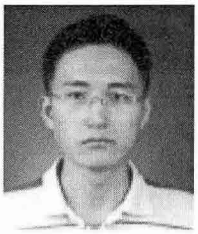

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