A Study on Layer 1 Network with Low Power Consumption for Data Relay Satellite

Yuta Takemoto, Yoshiaki Konishi, Takashi Sugihara
Information Technology R&D Center
Mitsubishi Electric Corporation
5-1-1 Ofuna Kamakura, Kanagawa 247-8501,Japan
Takemoto.Yuta@dn.MitsubishiElectric.co.jp

Tomohiro Araki
Aerospace Research and Development Directorate
Japan Aerospace Exploration Agency (JAXA)
2-1-1, Sengen, Tsukuba, Ibaraki, 305-8505 Japan

***Abstract*— We study the optical data relay satellite system on layer 1 network with low power consumption for data relay satellite, that focus on FEC function. The data relay satellite system is that LEO satellite and ground station communicate with each other via the data relay satellite. In this paper, we propose the system configuration that the data relay satellite has no FEC decoder. We compare the BER performance of the data relay satellite with FEC decoder and without FEC decoder. We use the Reed-Solomon encoder and decoder in this study. As a result, we show almost the same BER between the data relay satellite with FEC decoder and without decoder that the section between the data relay satellite and ground station is under the BER of 1.0×10^{-3}.**

Keywords—Data Relay Satellite; Forword Error Correction; Laser Communication; LEO; GEO;

I. Introduction

Low Earth Orbit (LEO) satellites are used on earth observation satellites for a purpose of environment observation. It is necessary to send data to the ground, such as weather data that LEO satellite has collected. In addition, the number of satellites is increasing [1]. However, LEO satellite has only about 60 minutes communication time per day with the ground station because it orbits the earth at high speed. Recently, long communication time has been required because earth observation satellites has gathered and transmitted a lot of information [2]. It is proposed that LEO satellite uses a data relay satellite system to increase the time of communication with the ground station [3]. Using the data relay satellite system, communication time can be increased 10 times or more. The data relay satellite system use Geostationary Earth Orbit (GEO) satellite, and the data collected in LEO satellite is transmitted to the ground station through the GEO satellite [4]. Therefore, the data relay satellite system must be a robust system which is capable of changing the satellite configuration, e.g. the relayed satellite and the number of relaying.

The data relay satellite system needs Forward Error Correction (FEC) for example Reed-Solomon codes [5]. That is because it is not able to maintain the communication quality that the distance between LEO and GEO and between GEO and the ground station are too long to communicate. If the data relay satellite has FEC function, the communication error might be negligible, but power consumption might be increased. Reducing the power consumption of satellite is desired, because the launch cost is increased with increase of the weight of the satellite caused by additional power module [6]. Thus, for example, there is a method that only the LEO satellite has FEC encoder and the ground station has FEC decoder [7]. This method doesn't support the change of satellite configuration flexibly when the FEC performance was determined by the state of communication path by specific configuration of the data relay satellite system.

In this paper, we show the system configuration of a optical data relay satellite system with low power consumption which is capable of the changing the satellite configuration, focusing on the FEC function.

II. System configuration

We propose the optical data relay satellite system on which the data relay satellite has only FEC encoder, and does not have FEC decoder. It is shown in Figure **1**. FEC data generated by LEO satellite is sent to the data relay satellite. The FEC data is encoded by the data relay satellite, and then, send to the ground station. The ground station decodes all FEC data. Generally, power consumption of FEC encoding is lower than that of FEC decoding. For example, we show a power consumption of Reed-Solomon (255,239) encoder and decoder, convolutional encoder and Viterbi decoder in Field Programmable Gate Array (FPGA). It is shown in Table 1, and the condition of the estimation is shown in Table 2. Reed-Solomon (255,239) power consumption of decoder is 3.25 times as high as that of encoder. The power consumption of Viterbi decoder is 65.3 times as high as that of convolutional encoder. Therefore, low power consumption data relay satellite system is realized using the data relay satellite with FEC encoder only. Three paths on which the data transmit are shown in Figure 2. First path is that the LEO satellite uses the data relay satellite #1. Second path is that the LEO satellite uses the data relay satellite #2. Finally, the third path is that the LEO satellite uses the data relay satellite #1 and #2. These paths are different BER. When the using path is changed from clean path to noisy path, if the data relay satellite has no FEC function, LEO satellite doesn't communicate with ground station. The our proposing system can support the change of satellite configuration flexibly, because all FEC data are decoded at the ground station and each data relay satellites encode the received data for communication with next satellite only.

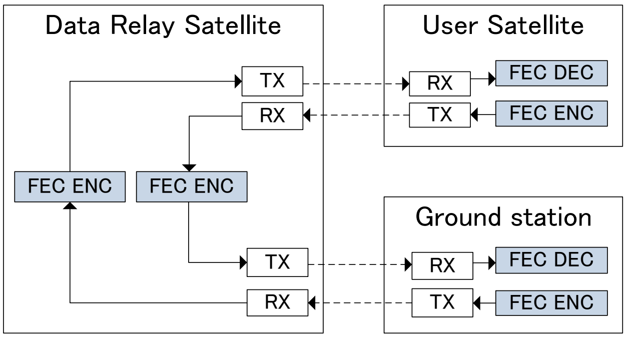

Figure 1 System configuration

Table 1 Compare of power consumption

	Power consumption	
	Reed-Solomon (255,239)	Convolutional code + Viterbi decode
DEC	0.65[W]	17.64[W]
ENC	0.20[W]	0.27[W]

Table 2 Condition of study

Method	Convolutional code + Viterbi decode	Reed-Solomon (255,239)
Constraint length	3	-
Coded rate	1/2	239/255
Bit rate	2.5Gbit/s	

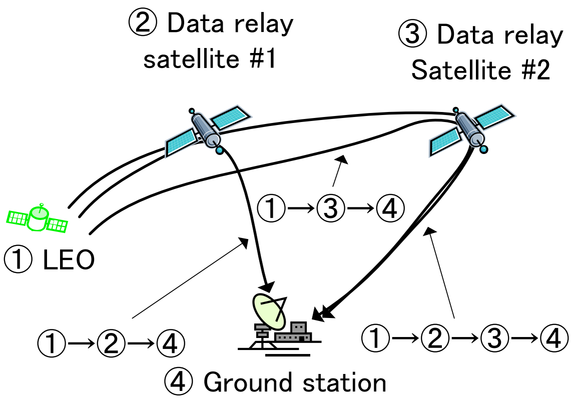

Figure 2 Data relay path

III. Configuration of error correction

Three configurations of FEC function are shown in Figure 3. We consider that there is one data relay satellite in this study. The LEO satellite sends a FEC encoding data to ground through the data relay satellite on all configurations. (a) is a configuration with no FEC function of the data relay satellite. (b) is a configuration with one FEC decoder and two FEC encoder of the data relay satellite. (c) is a configuration with one FEC encoder of data relay satellite. Configuration (b) decodes the data on the data relay satellite, but configuration(c) doesn't decode the data on the data relay satellite. Thus, the received data not to be corrected is just encoded and sent to the ground station in the configuration (c).

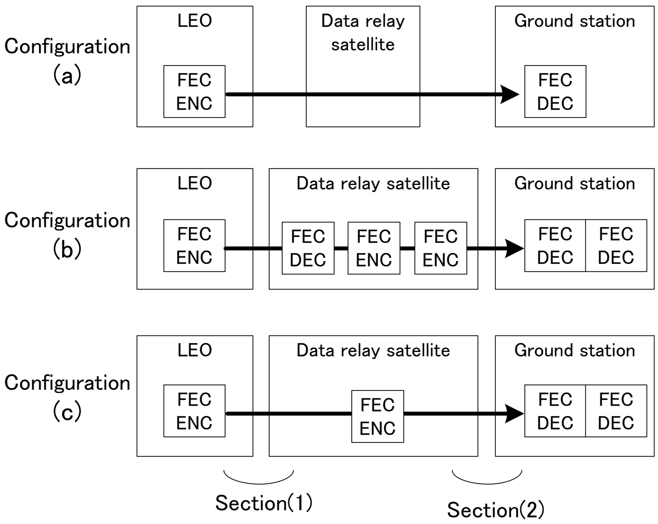

Figure 3 Configurations of FEC function

IV. The comparison of performance with Reed-Solomon error correction

In this paper, we study configurations of FEC function on the data relay satellite. Therefore, we compare the error correct performance of configuration (b) and configuration (c) in Figure 3. We assume that the data relay satellite system is simple model for BER calculation. In this study, we consider that there is error occurrence only once at same bit in both sections.

In Figure 4, we show the sequence that the data encode and decode on configuration (b) in Figure 3. In Figure 4, FEC(A) and FEC(B) is Reed-Solomon (239,223), and FEC(C) is Reed-Solomon (255,239). In section (2) FEC consists of a concatenated code. In Figure 5, we show the sequence that the data encode and decode on configuration (c) in Figure 3. In Figure 5, FEC(D) is Reed-Solomon (239,223), and FEC(E) is Reed-Solomon (255,239). FEC(D) is decoded at the ground station. To be these FEC configurations can be the same rate of transmission.

The study conditions are shown in Table 3. In order to evaluate that the total BER influence of changing BER of each section, the BER has fixed and the other BER has changed. The graph of Case1 in Table 3 is shown in Figure 6. The condition is that the BER of Section (1) is changed, and the BER of Section (2) is fixed. Its vertical axis is for the Total BER when the data is transmitted from the LEO satellite to ground station. The graph of Case2 in Table 3 is shown in Figure 7. The condition is that the BER of Section (2) is changed, and the BER of Section (1) is fixed. The graph of Case3 in Table 3 is shown in Figure 8. The condition is that the BER of Section (2) is changed, and the BER of Section (1) is fixed.

In these graphs, the BER of configuration (b) is shown by circle marker, and the BER of configuration (c) is shown by plus marker. In the Figure 6, there are almost the same BER between configuration (b) and configuration (c). Therefore, in case of changing the BER of section (1), there is almost no influence whether the data relay satellite has FEC or not. For example, the total BER of configuration (b) is $7.39 \times 10^{-7}$and the total BER of configuration (c) is 7.33×10^{-7}, when the BER of section (1) is 1.0×10^{-3} and the BER of section (2) is 1.0×10^{-3}. In the Figure 7, the performance of configuration (b) is better than configuration (c) between $2.5 \times 10^{-3} \sim 4.0 \times 10^{-3}$ of the BER of section (2). There is maximum difference when the BER of section (2) is 3.5×10^{-3}, total BER are 3.6×10^{-5} of configuration (c) and 8.4×10^{-7} of configuration (b).On the other hand, the region under the BER of 1.0×10^{-3} of section (2) shows almost the same performance because the BER of section (1) is dominant. In the Figure 8, configuration (b) performance is higher than configuration (c) between $2.0 \times 10^{-3} \sim 2.5 \times 10^{-3}$ of the BER of section (2). There is the difference when the BER of section (2) is 2.0×10^{-3}, total BER are 1.6×10^{-12} of configuration (c) and 7.4×10^{-15} of configuration (b). This difference is not important because both BER are enough low for satellite communication system.

The total BER of configuration (c) is higher than the total BER of configuration (b) in Figure 7 and Figure 8. The reason is that there is residual error data of FEC(E).The error data influence the correction performance of FEC(D). This sequence is shown in Figure 9. The performance of Reed-Solomon (239,223) is shown in Figure 10 [7]. In the Figure 10, the correction performance begins to fall when the Input BER become about over 2.0×10^{-3}. Thus, the error data of FEC(E) accelerate the enter the over 2.0×10^{-3} area, and the configuration(b) performance of error correction is lower than configuration(c).

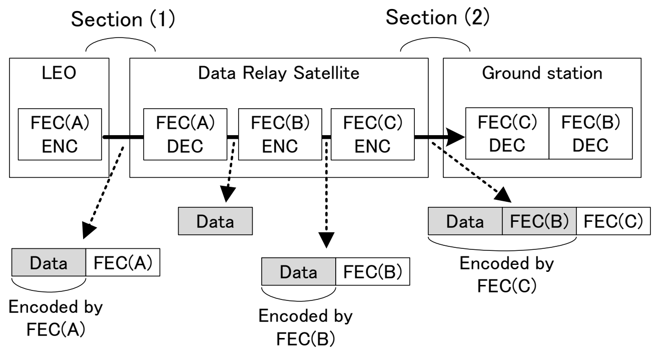

Figure 4 Configuration of FEC function (Configuration (b))

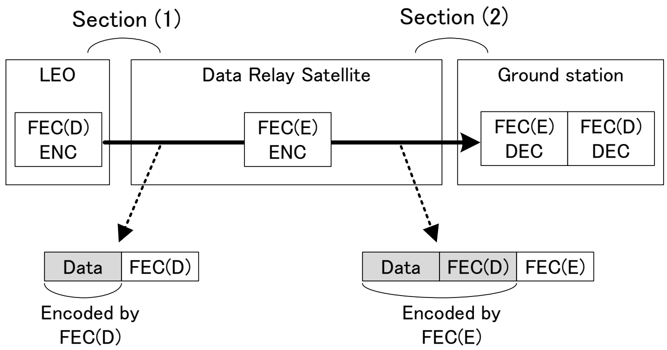

Figure 5 Configuration of FEC function (Configuration(c))

Table 3 Error rate of each section on this study

	BER of Section(1)	BER of Section(2)
Case1 (Figure 6)	$1.0 \times 10^{-4} \sim 5.0 \times 10^{-3}$	1.0×10^{-3}
Case2 (Figure 7)	1.0×10^{-3}	$1.0 \times 10^{-4} \sim 5.0 \times 10^{-3}$
Case3 (Figure 8)	1.0×10^{-4}	$1.0 \times 10^{-4} \sim 5.0 \times 10^{-3}$

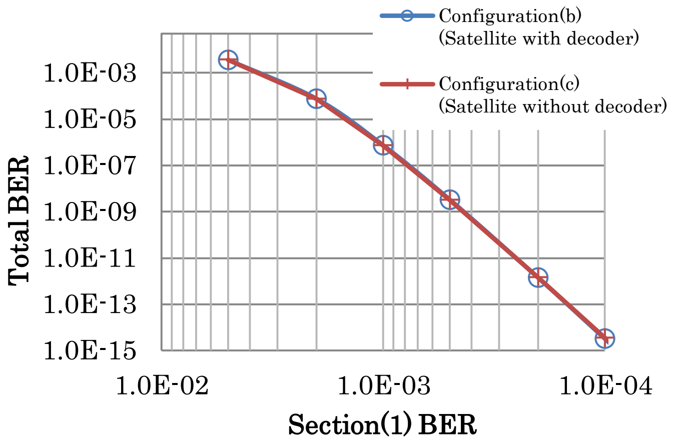

Figure 6 The influence of changing BER of the section (1) (section(2) BER = $\mathbf{1.0} \times \mathbf{10^{-4}}$)

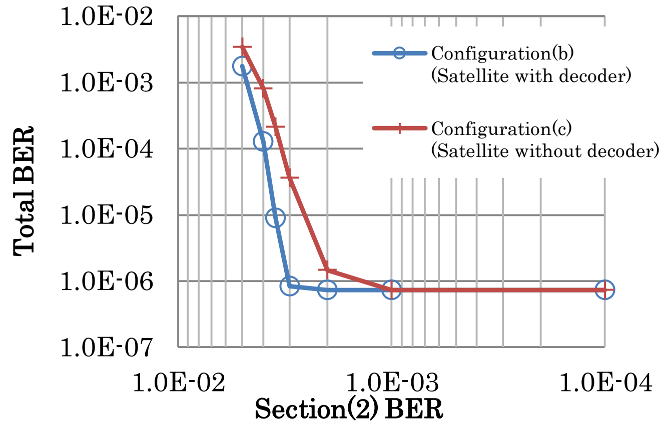

Figure 7 The influence of changing BER of the section (2) (section(1) BER = $\mathbf{1.0} \times \mathbf{10^{-3}}$)

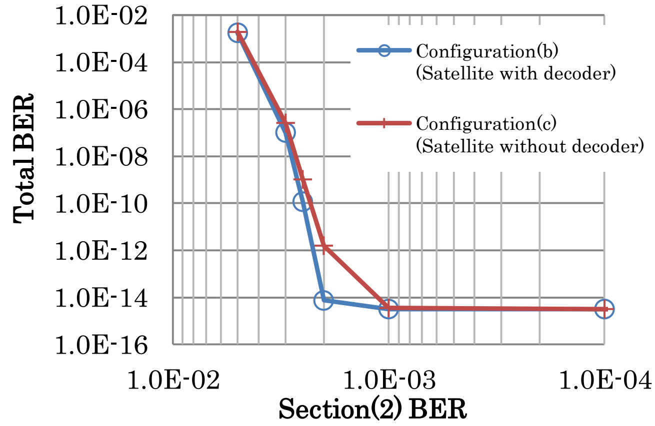

Figure 8 The influence of changing BER of the section (2) (section(1) BER = $\mathbf{1.0} \times \mathbf{10^{-4}}$)

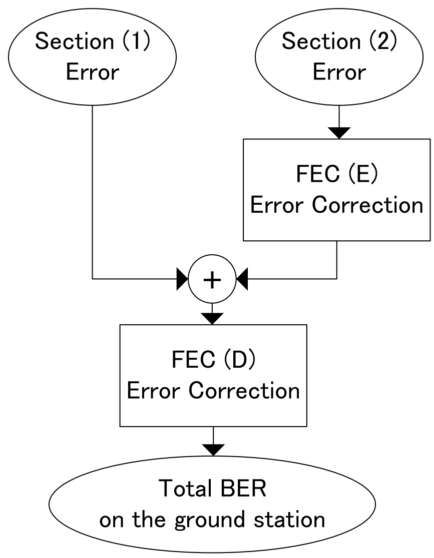

Figure 9 Procedure of error correction (Configuration(c))

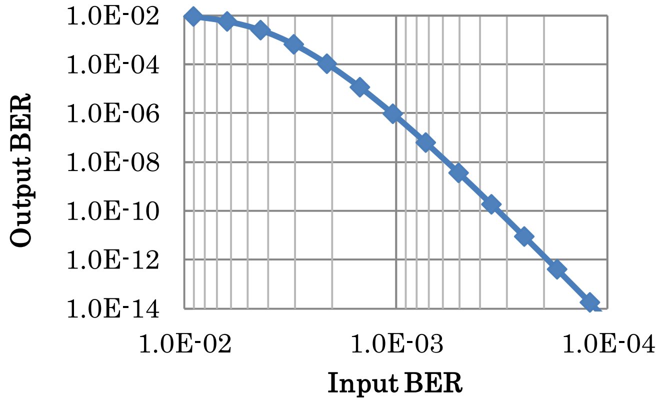

Figure 10 Reed-Solomon (239,223) Input BER vs Output BER

V. Conclusion

We study FEC configuration of the optical data relay satellite system and we propose the configuration in which the data relay satellite has FEC encoder only. This configuration realizes low power consumption and robust system of the data relay satellite. In addition, we estimate FEC performance of the various configurations. As a result, we show almost the same performance of the BER in the condition of changing the BER of the section between the LEO and the data relay satellite. However, changing the BER of the section between the data relay satellite and ground station, the FEC performance degrades in some conditions. When using the proposed configuration, we should design the system on which BER of the section between the data relay satellite and ground station under the BER of 1.0×10^{-3}.

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