Study on Coding Parameters for a Small Optical Transponder

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Abstract—**We recently developed a small optical transponder (SOTA) for a 50-kg-class satellite. The SOTA is equipped with modules for processing error-correcting codes. In this paper, we present the results of a study on the parameters of error correcting codes by experimenting with ground-to-satellite laser communication links. In order to do this, a SOTA simulator (SOTA-SIM) was designed. We demonstrate optical communication between buildings using low-density generator matrix (LDGM) code at distance of 7.8 km. The demonstration was to study how the coding parameters, code rate, and interleaving depth affect the quality.**

Keywords—small optical transponder; SOTA; optical communication; error correcting; LDGM

I. INTRODUCTION

In recent years, the size of high-resolution images and data in observation equipment have increased because of the advances in satellite functionality. Therefore, it is necessary to increase the speed of the communication links between the ground and the satellites. Higher-capacity faster communication will be required in the future. In their present form, widely used radio-frequency communication is incapable of achieving communication speeds of several dozens of gigabits per second because they are limited by the carrier wave frequency. Satellite optical communication technology is currently being considered as a solution to this issue. The quality of the ground-to-space signal as it passes through the atmosphere is adversely affected by the variations in the atmosphere. One method to reduce this deterioration in communication quality is encoding the communication data.

The National Institute of Information and Communications Technology (NICT) recently completed a small optical transponder (SOTA) for the Space Optical Communications Research Advanced Technology Satellite (SOCRATES) project, which launched a 50-kg-class satellite in 2013 [1]. The establishment of an optical communication link is the main mission of this project. SOTA is equipped with four lasers and employs the Reed–Solomon and low-density generator matrix (LDGM) error correcting codes [2]. We studied the parameters for the LDGM error correcting codes by experimenting with the ground-to-satellite laser communication links. We built an optical terminal simulator for the SOTA. The SOTA-SIM has the same functions as the SOTA proto-flight model.

In this paper, we demonstrate optical communication between buildings at a distance of 7.8 km using LDGM code in the SOTA-SIM. We change the coding parameters, code rate, and interleave depth and observe its effect on quality.

II. DEMONSTRATION CONFIGURATION

A. Demonstaration Outline

Fig. 1 shows the demonstration configuration. An optical communication link was established between two buildings using the LDGM code and SOTA-SIM. The two points were located at a distance of 7.8 km apart. The SOTA-SIM was located at Point A, and a receiver was placed at Point B. The demonstration was conducted as follows. First, the receiving system emitted a beacon light. The SOTA-SIM at the transmission side received this beacon and projected a communication laser in the direction of the beacon while tracking it. The SOTA-SIM can communicate at speeds of 1 Mbps and 10 Mbps. We set the speed as 10 Mbps for the demonstration. Because the transmission power of the SOTA-SIM was locked, the receiving optical system adjusted the receiving power. The bit error rate was varied from 10^{-1} to 10^{-6} during the demonstration. An internet packet format was used for the communication. Packet errors were detected using the checksum in the internet packet.
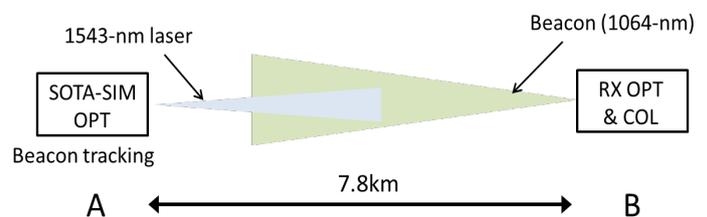

Fig. 1. Demonstration configuration.

Experimental parameters		
Distance	7.8	km
Error correcting code	LDGM	
Data rate	10	Mbps
TX laser	1550	nm
Beacon laser of RX	1064	nm

B. Small Optical Transponder

The primary objective of the SOTA is to enable ground-to-satellite optical communication experiments. Fig. 2 shows a photograph of the SOTA-SIM in a dust protection box. The SOTA-SIM is equipped with four lasers: TX1, TX2, TX3, and TX4. TX1 and TX4 operate at wavelengths of 976 nm and 1549 nm, respectively. TX2 and TX3 use 800-nm lasers to gather basic data for future quantum-key distribution [1].

Table II lists the laser transmitter and receiver parameters of the SOTA. The demonstration was conducted using the 1550-nm laser for TX and 1064-nm laser for RX. The SOTA-SIM tracked the 1064-nm laser using a quadrant detector (QD) sensor and a fast-pointing mirror during the demonstration .

TABLE II.   LASER TRANSMITTERS AND RECEIVER OF THE SOTA-SIM

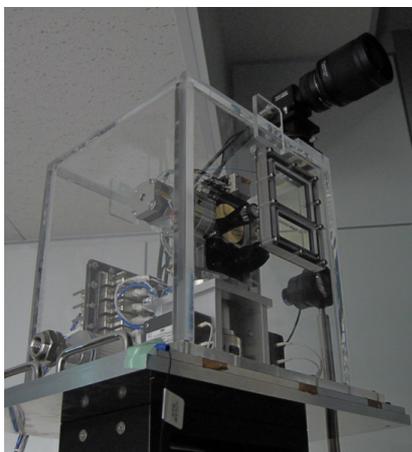| Laser transmitters and receiver			
Wavelength	TX1	980	nm
	TX2 & 3	800	nm
	TX4	1550	nm
	RX	1064	nm
Data rate		1 / 10	Mbps
RX antenna diameter		5	cm

Fig. 2. Photograph of the SOTA-SIM.

C. Receiving System

Fig. 3 shows the receiving system that uses a 1550-nm laser for reception and emitted a beacon with a 1064-nm laser. The receiving system does not perform active operations during optical communication. The beacon laser was a continuous wave source and had a divergence angle of 1 mrad. The telescope aperture was 10 cm. In order to adjust the received power, it is possible to insert an ND filter in the middle of the receiving optical system.
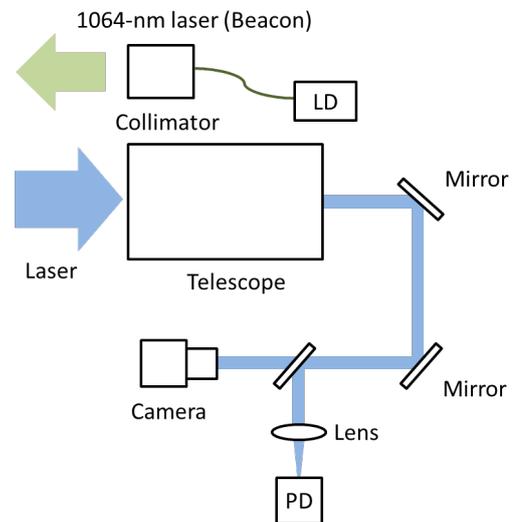

Fig. 3. Configuration of reciver.

D. Error Correcting Parameters of the LDGM

The LDGM code is a type of LDPC code and is specialized for erasure correction. LDPC has a correction capability close to the Shannon limit. Normal LDPCs require a generator matrix in addition to the transmit data and check matrix. On the other hand, LDGM codes can generate code data directly from the check matrix. This reduces the number of calculations and uses less memory than LDPC codes. Fast decoding using parallel processing is also under investigation for this code.

Table III lists the coding parameters. We evaluated the performance of the LDGM code by changing the code rate and interleave depth for a fixed code length of 1000 and a Galois field index of eight. We used block interleave for the demonstration. In our case, the interleave depths of 10 and 100 are equal to 0.5 ms and 5 ms, respectively.

TABLE III.   LDGM PARAMETERS

Parameters	Values		
	Case1	Case2	Case3
Galois field	GF(2^8)		
Code length	1000 (Symbol)		
Code rate	0.5	0.25	0.1
Weight (k, j)	7, 7	4, 16	3, 27
Interleave depth	1, 10, 100 (Number of blocks)		

III. RESULTS OF THE DEMONSTRATION

Figs. 4–6 show the results of the demonstration. The bit error rate calculated from the received packet data is plotted on the x-axis. The y-axis plots the probability of error remaining after error correction. It shows that the LDGM codes were not able to correct received data by the error correcting code at a probability of one, and it is possible to correcting all at a probability of zero. The value of C_n^2 was between 10^{-14}–10^{-15} in the demonstrations.
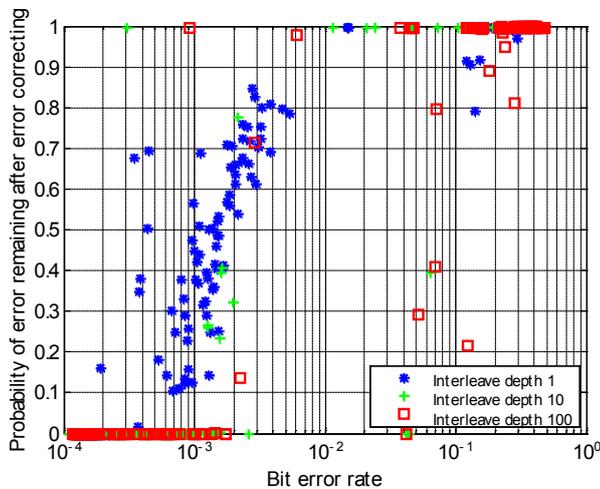

Fig. 4. Comparison of the error-correcting capability at different interleave depths using an LDGM with a code rate of 0.5.
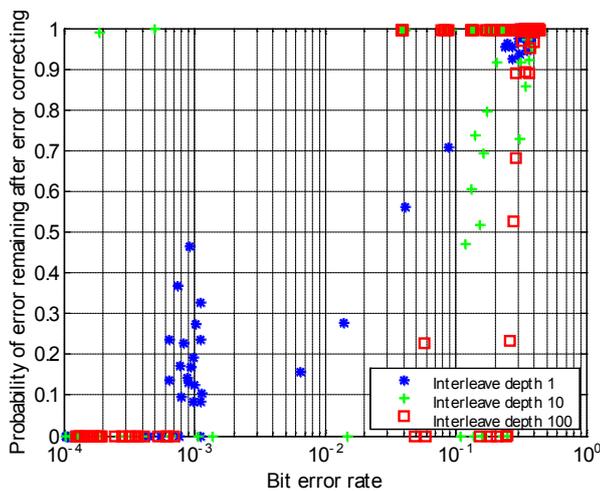

Fig. 5. Comparison of the error-correcting capability at different interleave depths using an LDGM with a code rate of 0.25.
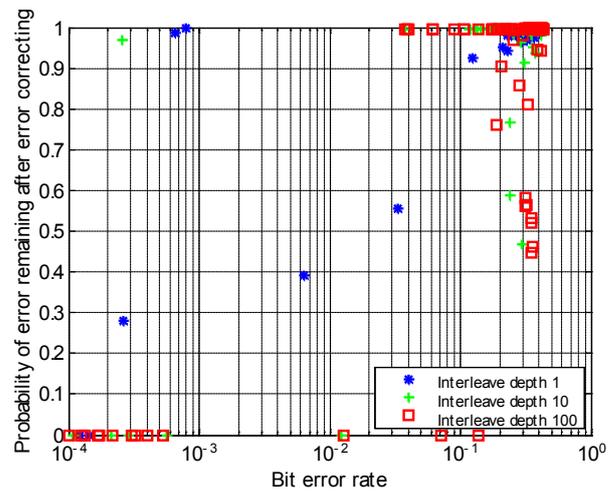

Fig. 6. Comparison of the error-correcting capability at different interleave depths using an LDGM with a code rate of 0.1.

The probability of error correction increases as the interleave depth increases. There are cases where many errors remain after error correction, even though the bit error rate is small. We think this is because of a burst error event that occurs occasionally. We observed that the LGDM code could correct errors at a low-quality BER because the ability of error correcting is increased when the code rate is smaller.

IV. CONCLUSION

This study demonstrates the use of an LDGM for optical communications between buildings. An optical communication demonstration was conducted between two buildings using LDGM codes and an SOTA-SIM. The two buildings were separated by 7.8 km. We evaluated the performance of the LDGM codes by changing the code rate and interleave depth for a fixed code length of 1000 and a Galois field index of eight.

The probability of being able to correct the error data increases with interleave depth. There were cases where many errors remained after error correction, even though the bit error rate was small. We think this was because of burst errors, which occur occasionally. We observed that the LGDM code can correct errors at low BERs because the error-correcting ability increased when the code rate was smaller. We plan to run a burst-error time analysis in the future.

REFERENCES

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