3-10 Experiment Report of Satellite Communication at the Ocean

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Recently, the observation data transmission and the picture transmission for the monitoring of observation status are being considered because the development of the technology for the ocean resource exploration is advanced. NICT is developing the high-speed communication technology using a satellite because it is necessary to structure Mbps link for achieving these objectives. In this paper, we describe the results of examination to confirm a satellite tracking performance and a communication performance at the ocean.

1 Introduction

The project entitled "Next-generation technology for ocean resources exploration" being pursued by the Cabinet Office's Cross-ministerial Strategic Innovation Promotion Program (SIP) has begun developing exploration technologies. An increasing need exists to transmit image data from ocean monitoring and data collected on the ocean floor to various research facilities [1][2]. Communications technologies currently available in waters surrounding Japan mostly consist of satellite communication systems with transmission speeds of several hundred kbps. However, communication systems with transmission speeds of several Mbps are necessary to meet the needs mentioned above. NICT is therefore developing satellite-based high-speed communication technologies and earth stations that will enable communication at sea at transmission speeds of several Mbps.

The WINDS (wideband internetworking engineering test and demonstration satellite) experiments have already achieved 3.2 Gbps data rates using an earth station equipped with a large antenna (2.4 m diameter). In addition, a 51 Mbps data rate was demonstrated by accessing WINDS using a 1.2 m diameter VSAT (very small aperture terminal) set in a regenerative mode. NICT is also developing land-mobile earth stations by mounting satellite tracking antennas on ordinary vehicles to enable satellite communication. These antennas also can be installed on marine-mobile earth stations using appropriate antenna mounts. The versatility of these antennas enables the construction of communication lines in a variety of areas. A marine mobile earth station was demonstrated in 2013 when JAMSTEC (Japan Agency for Marine-Earth Science and Technology) installed a WINDS-compatible marine earth station on its research ship *Kaiyo*, established a satellite communication line between the earth stations on the ship and on land via WINDS and remotely controlled a hybrid remotely operated vehicle (HROV), Otohime [3].

NICT is studying and developing compact, light and energy-efficient marine-based earth stations that can be installed not only on research ships but also on small ships and autonomous surface vehicles (ASVs). NICT is also developing antenna system carriers that will enable accurate satellite tracking even in high wave conditions. In this project, we carried out satellite communication experiments at sea using a WINDS-compatible marine-based earth station. The experimental objectives were to determine the station's satellite tracking capabilities and data transmission characteristics in relation to the effects of ship movement and waves by establishing a communication line and performing communication tests. This is a report on the results of the experiments carried out jointly with JAMSTEC on its ship at sea in January and February 2016.

2 Experiments at sea

We carried out studies aboard the JAMSTEC research ship *Mirai* at sea. The ship departed from the Shinko District (new harbor district) of Yokohama and traveled around Sagami Bay and Suruga Bay. We analyzed the satellite acquisition and tracking performance of the on-board earth station and performed satellite communications ex-

Fig. 1 External view of research vessel “Mirai”

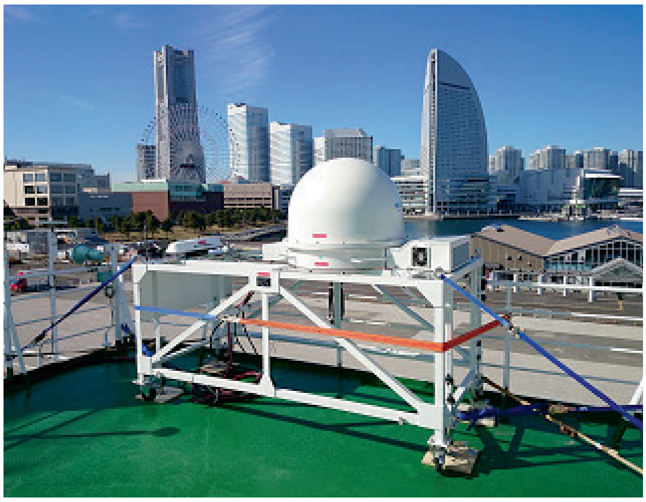

Fig. 2 External view of the earth station on board vessel for WINDS

periments. *Mirai* is shown in Fig. 1.

3 WINDS-compatible earth station

3.1 WINDS-compatible marine-based earth station

The appearance and specifications of the station installed on the *Mirai* are shown in Fig. 2 and Table 1, respectively. The station is equipped with an antenna system capable of acquiring and tracking satellites automatically and establishing communication lines even when the *Mirai* is moving. When set in regenerative mode, the WINDS station is able to establish communication lines capable of transmitting data at a maximum rate of 24 Mbps [4]. The station antenna estimates WINDS’ position based on the station’s current location and the strength of beacon signals received from WINDS and automatically acquires and tracks the satellite. The same antenna system has demonstrated the ability to track the satellite and establish communication lines when installed on a compact vehicle traveling at 100 km/h [5]. This satellite tracking antenna system is outlined below.

When in search mode, the satellite tracking antenna system estimates the station’s position by receiving GPS signals and detects the strength of beacon signals from the satellite to acquire WINDS. After the satellite is acquired, the antenna system switches to beacon tracking mode, which enables it to implement monopulse satellite tracking and establish communication lines while a vehicle is moving. If the antenna system is in beacon tracking mode and the reception of beacon signals is interrupted while the communication lines are in operation, it switches to a gyro holding mode, enabling it to re-estimate its current location and attitude using GPS signals. This process enables the antenna to reorient itself toward the satellite. If the beacon signal is not detected after more than 60 seconds, the antenna system switches back to satellite search mode to re-acquire the satellite using open-loop pointing. These satellite acquisition and tracking processes are shown in Fig. 3.

Table 1 Specifications of the earth station on board vessel for WINDS

Antenna	Cassegrain antenna(φ0.65 m)
Frequency	TX: 27.5 – 28.6 GHz RX: 17.7 – 18.8 GHz
Polarized wave	Linearly polarized
Antenna gain	TX: 42.5 dBi RX: 38.0 dBi
Output power	20 W
G/T	13.5 dB/K
Data rate	TX: 1.5/6/24 Mbps RX: 155 Mbps

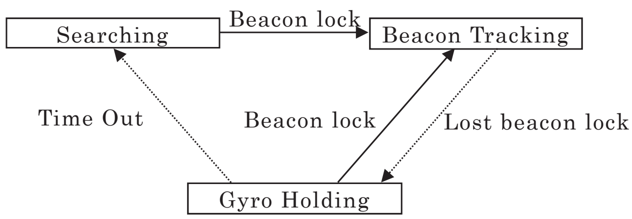

Fig. 3 Process of acquisition and tracking

3.2 51M-VSAT

We used the 51M-VSAT at the NICT Kashima Space Technology Center (Kashima City, Ibaraki Prefecture) as

Fig. 4 External view of 51M-VSAT

Table 2 Various element of 51M-VSAT

Antenna	Offset parabolic antenna(φ1.2 m)
Frequency	TX: 27.5 – 28.6 GHz RX: 17.7 – 18.8 GHz
Polarized wave	Linearly polarized
Antenna gain	TX: 47.6 dBi RX: 44.0 dBi
Output power	40 W
G/T	18.9 dB/K
Data rate	TX: 1.5/6/24/51 Mbps RX: 155 Mbps

an earth station to receive communications from the WINDS-compatible marine-based earth station installed on the research ship *Mirai*. The appearance and specifications of the 51M-VSAT are shown in Fig. 4 and Table 2, respectively. When WINDS is set in regenerative mode, the 51M-VSAT is able to establish communication lines capable of transmitting data at a maximum rate of 51 Mbps [4].

4 Experimental methods

4.1 Experimental network configuration

The experiment was carried out within range of the WINDS multi-beam antenna (MBA) [4]. A communication line was established using the MBA beam for the Chubu Region—which was received by the WINDS-compatible marine-based earth station traveling at sea—and the MBA beam for the Kanto Region which was received by the 51M-VSAT in Kashima. The experimental network configuration is illustrated in Fig. 5.

Each earth station is connected to a telephone conference system and a PC to measure throughput. The station on the ship is also connected to a second PC which logs

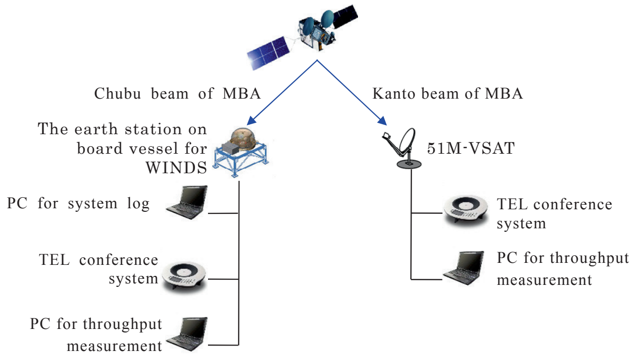

Fig. 5 Configuration diagram of experiment network

antenna movements and the C/N_0 (carrier-to-noise power ratio) levels of beacon signals from the satellite.

4.2 Experimental methods

(a) Experiments to confirm satellite tracking performance

The WINDS-compatible marine-based earth station can collect data on antenna movements, the C/N_0 levels of beacon signals received from the satellite, the station's location and its satellite tracking accuracy. We evaluated the satellite tracking performance of the station in relation to the effects of ship movement and waves.

(b) Experiments to confirm data transmission characteristics

We connected PCs to the IDUs (indoor units) of the earth stations both on the ship and in Kashima to measure the throughput of each station. The measurements were then used to analyze the transmission characteristics of TCP (Transport Control Protocol) communication between the two stations. These PCs, which run a Linux operating system, were used to evaluate congestion control techniques suitable for a time delay environment. We also examined the transmission of UDP (User Datagram Protocol) communications, which are used to transmit image and audio data. In addition, we analyzed transmission characteristics of TCP and UDP communications using iperf [6].

5 Experimental results

5.1 Satellite tracking characteristics of the WINDS-compatible marine-based earth station

The ship travelled continuously and was constantly affected by waves during the experiment. We investigated the relationship between antenna movement and the C/N_0 levels of beacon signals from the satellite while the ship

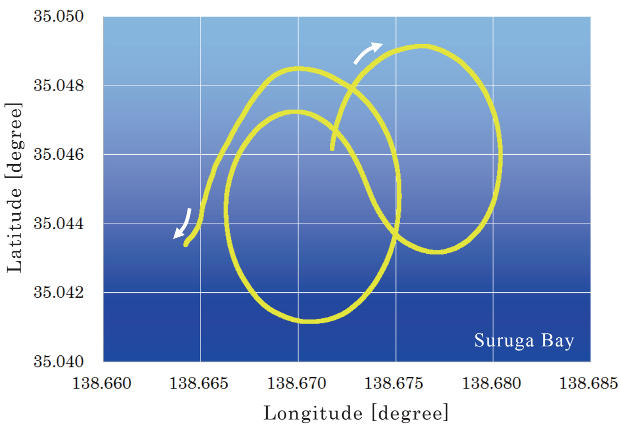

Fig. 6 Trajectory of figure eight cruise

Fig. 7 Something to block on research vessel

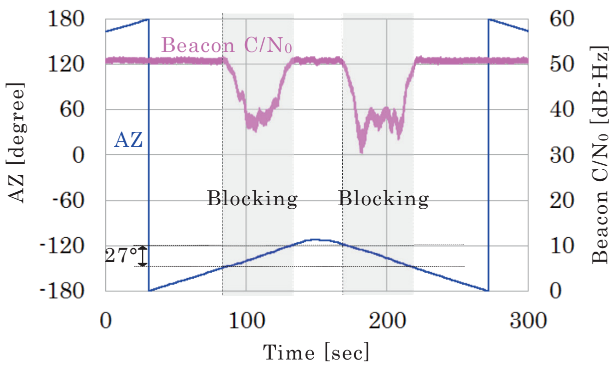

Fig. 8 Verification of communication blocking area

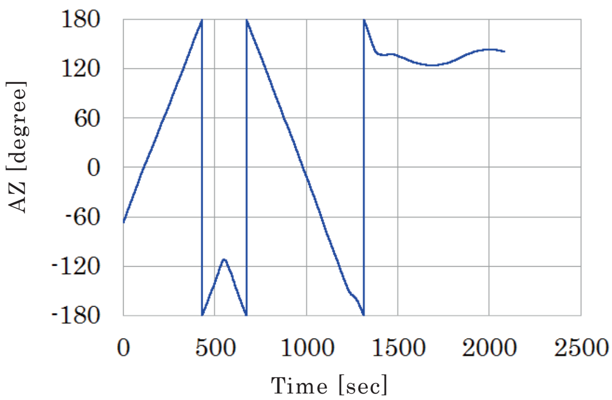

Fig. 9 The angle of azimuth motion situation of the antenna at cruise of figure eight

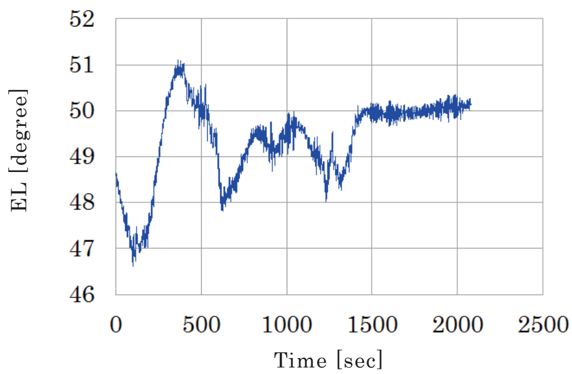

Fig. 10 The angle of elevation motion situation of the antenna at cruise of figure eight

traveled in figure-eight patterns to understand the satellite tracking characteristics of the WINDS-compatible marine-based earth station.

The ship's figure-eight course is shown in Fig. 6. The fixed object on the ship deck shown in Fig. 7 sometimes blocked transmission between the onboard earth station and the satellite, causing communication loss and interruption, when the ship was oriented in a certain direction. The relationship between the azimuth (AZ) of the antenna and the C/N_0 level of beacon signals from the satellite was analyzed (Fig. 8) to determine the AZ range within which the onboard object interrupts communication. Antenna AZ to the right and left with respect to the ship's bow direction (0°) are represented by positive and negative values, respectively. Communication was interrupted when the ship was oriented in a northwestly direction and the satellite was positioned almost due south (i.e., when the antenna AZ was between -120° and -147°) (Fig. 8).

The movement of the satellite tracking antenna in terms of AZ and elevation (EL) is shown in Figs. 9 and 10, respectively, in relation to the ship traveling in figure-eight patterns. In addition, the C/N_0 levels of beacon signals from the satellite are shown in Fig. 11.

The antenna accurately tracked the satellite during radical ship movements. We confirmed normal antenna movement (Figs. 9 and 10) and stable beacon signal reception (Fig. 11). The antenna continuously tracked the satellite except when the fixed object on the ship deck (Fig. 7) interrupted communications. The margin of error for the

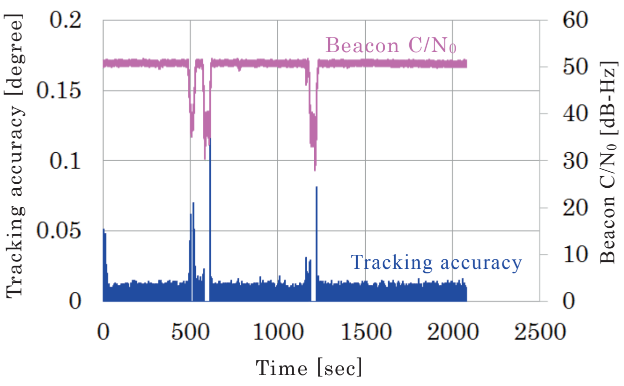

Fig. 11 Tracking accuracy at cruise of figure eight

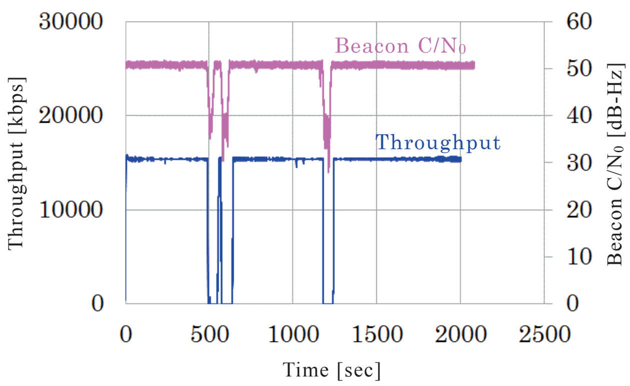

Fig. 12 TCP throughput at cruise of figure eight

satellite tracking accuracy of the WINDS-compatible marine-based earth station has been set to be ±0.2°. When errors exceed this range, an interlock function is activated which stops radio wave transmission by the station.

The station's satellite tracking accuracy is shown in Fig. 11. These results confirmed that the tracking control system functioned adequately within the ±0.2° error margin when the ship was traveling in figure-eight patterns. The station was unable to receive beacon signals from the satellite when the object on the ship deck (Fig. 7) obstructed satellite communications. However, the station reacquired the satellite immediately after the object was no longer in its path. This observation confirmed that the gyro holding system was functioning normally.

5.2 Transmission characteristics of TCP communications when the ship was traveling in a figure-eight pattern

We established a WINDS communication line that was set at a data transmission rate of 24 Mbps and transmitted TCP data through the line while the ship traveled in figure-eight patterns as described in Subsection **5.1**. Data throughput during this experiment is shown in Fig. 12. The C/N_0 levels of the beacon signals indicated in Fig. 11 were also superimposed on this figure to illustrate the effect of the communication interruption caused by the fixed object on the ship deck on data throughput. We measured TCP throughput using congestion control algorithms tuned to WINDS [7].

When the station is unable to receive beacon signals due to obstruction by the object on the ship deck, an interlock function is activated to stop radio wave transmission by the station. Once the object no longer impedes transmission, the station resumes receiving beacon signals and transmitting radio waves. The line speed reached maximum within several seconds after the resumption of communications, indicating that TCP communication was stable when the ship was traveling in a figure-eight pattern, except when the object on the deck obstructed communications.

5.3 Transmission characteristics of TCP communication via WINDS at different data rates

Major communication delay occurs in satellite communications due to extremely long transmission paths. The use of TCP communication in such systems sometimes does not allow full utilization of a communication line's network bandwidth. Congestion control techniques, which control data transmission volume based on RTT (round-trip time) values, are effective in addressing this issue [7]. In addition, previous studies confirmed that techniques to control data transmission volume which account for communication line conditions further stabilize communication [7]. We compared the data transmission characteristics of TCP communication using two procedures: congestion control algorithms tuned to WINDS communication lines (TCP for the WINDS network) and Linux-based (CUBIC) congestion control algorithms [7][8]. The throughputs of the WINDS communication lines were measured at different data rate settings (Table 3). Temporal changes in throughput measurements using TCP for the WINDS network and CUBIC are shown in Figs. 13 and 14, respectively. These measurements were carried out while the data rate was set at 24 Mbps.

The throughput difference between the two types of congestion control algorithms was small at the 6 Mbps network bandwidth setting (Table 3). However, throughput differences between the two increased with increased network bandwidth. When the data rate was set at 51 Mbps,

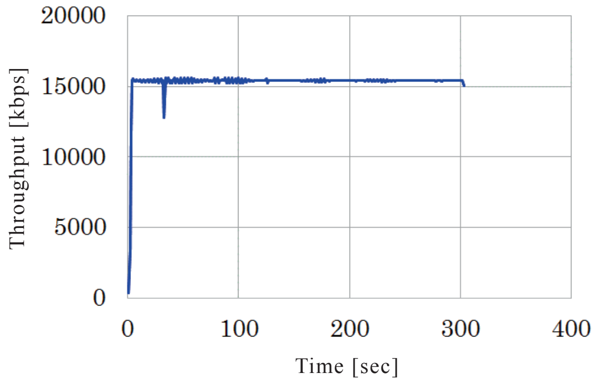

Fig. 13 Throughput variation of TCP congestion control for WINDS

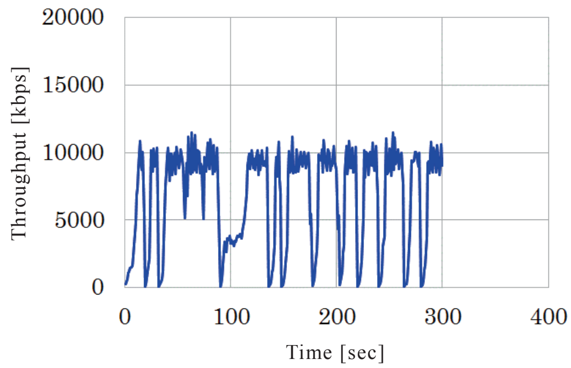

Fig. 14 Throughput variation of CUBIC

Table 3 Comparing of throughput for congestion control

WINDS link data rate	Congestion control	
	TCP for WINDS	CUBIC
6Mbps	3.912 Mbps	3.731 Mbps
24Mbps	15.052 Mbps	6.851 Mbps
51Mbps	29.772 Mbps	7.774 Mbps

Table 4 Theoretical and Actual of data rate for slot setting of 288

WINDS link data rate	Theoretical value of network bandwidth	Actual data rate of TCP
6Mbps	5.105 Mbps	4.457 Mbps
24Mbps	19.143 Mbps	16.712 Mbps
51Mbps	38.286 Mbps	33.424 Mbps

the throughput associated with TCP for the WINDS network was 30 Mbps; almost quadruple the throughput associated with CUBIC.

When WINDS is set in regenerative mode, it processes received data using ABS (on-board asynchronous transfer mode baseband switch) [4]. To enable compatibility with this process, earth stations transmit uniquely formatted data to the satellite. This format, called an MPEG-TS stream, has been confirmed to be capable of achieving data transmission volume as high as approximately 87.3% of theoretical network bandwidth [7]. The WINDS regenerative mode uses the TDMA (time division multiple access) method, which employs superframes composed of 320 slots/frame. In our experiments, we established a line to the satellite which transmitted data using 288 slots, excluding information slots. Actual data rates using the 288 slots were measured at different data transfer speed settings (Table 4).

The comparison between the throughput measurements in Table 3 and the actual data rates in Table 4 revealed that the general-use CUBIC congestion control algorithms do not allow efficient bandwidth utilization, while the congestion control algorithms tuned to WINDS do. In addition, when the CUBIC algorithms were used, it took the communication line more than 10 seconds to reach maximum throughput. In comparison, when the algorithms tuned to WINDS were used, it took only three to four seconds.

These results confirmed that congestion control algorithms capable of controlling TCP window sizes which account for delay and line status effectively facilitate satellite communications that are susceptible to long delays.

5.4 Transmission characteristics of UDP communication

Unlike TCP communication, UDP communication transmits data without establishing sessions [9]. For this reason, UDP communication is capable of high-speed data processing although it is unable to resend data when packets are lost. We performed data transmission measurements associated with UDP communication because this communication mode enabled us to detect packet losses in transmission channels without causing communication delays and to analyze transmission channel capacities. UDP communication measurements using iperf also allowed us

Table 5 Network bandwidth of WINDS link for UDP

WINDS link	Network bandwidth of UDP
6Mbps	4.6Mbps
24Mbps	18Mbps
51Mbps	36Mbps

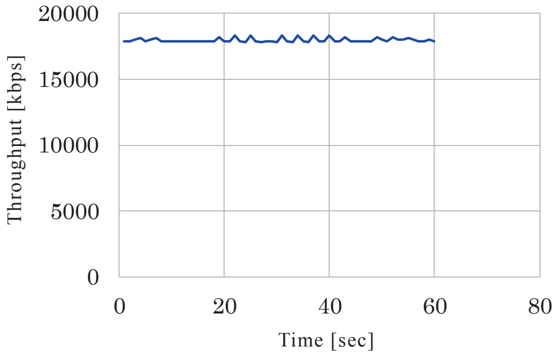

Fig. 15 Variation of network bandwidth for UDP

to set the data volume to be transmitted in advance. Thus, this method enabled us to measure transmission channels' maximum capacities without packet loss. Capacity measurements at different data rate settings are shown in Table 5. Changes in the WINDS communication line throughput were measured for one minute. The 24 Mbps setting results are shown in Fig. 15 as an example.

Header data volume in UDP communication was lower than in TCP communication, indicating that UDP communication throughput is virtually the same as the theoretical network bandwidth when WINDS is set in regenerative mode. In addition, UDP communication throughput reached the preset data rate as soon as measurement began, and remained virtually constant with only slight fluctuations as the ship traveled. Thus, we confirmed stable communication during this experiment.

6 Conclusion

We studied the satellite acquisition and tracking characteristics of a marine-based earth station during oceanic travel by a station-equipped ship. The satellite tracking performance of the station was satisfactory, indicating that both TCP and UDP communications functioned stably. We were able to maximize the capacity of the TCP communication line using congestion control algorithms tuned to WINDS.

An open ocean satellite communication system would offer the advantage of flexible networking of multiple bases via satellite, enabling data to be transmitted at a constant rate between the bases no matter how distant they are from each other. A constant transmission rate can be achieved across the satellite communication range. In future studies, it will be important to develop compact, light and energy-efficient earth stations that can be used to establish communication lines with several Mbps of capacity not only in the WINDS MBA range but also in the APAA (active phased array antenna) range, which mostly consists of ocean areas [4]. We plan to test these earth stations on the ocean once they are developed, establish communication lines with several Mbps of capacity, establish an oceanic network and consider its effective use.

Acknowledgment

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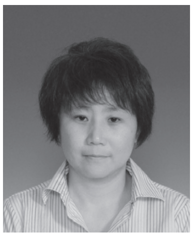

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