3-11 A Measurement of Propagation in High Mobility Environments for Ka Band Satellite Communication

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Satellite communication has attracted attention as an effective means of communication in an emergency such as a disaster. National Institute of Information and Communications Technology (NICT) has developed a small-vehicle stations equipped with the antenna system for automatic tracking for the Wideband InterNetworking engineering test and Demonstration Satellite "KIZUNA" (WINDS), it has become possible to build a satellite line while moving. In this study, we report radio wave propagation measurements assuming the Nankai Trough earthquake in Ka-band satellite communications under a fast-moving environment in Shikoku and Kinki area, Kyusyu area, and the Coast of japan sea of western Japan.

1 ntroduction

At the time of a large-scale disaster, information and communication technology provides essential tools for grasping situations and collecting information on disaster stricken areas, and for sharing information in rescue operations. Even in the case where terrestrial communication systems are severely disabled, satellite communication can provide an alternative communication. NICT has been conducting research on a high-speed internet satellite called WINDS (Wideband InterNetworking engineering test and Demonstration Satellite)[1]. The project includes the development and operation of an earth station mounted on a van called a vehicle earth station. The vehicle earth station is equipped with an antenna system capable of automatically detecting, tracking, and communicating with the WINDS satellite while it is running[2].

Understanding for the propagation environment is an important factor when constructing a communication system. NICT has conducted communication propagation measurements between a satellite and earth station on the moving vehicle earth station. Bearing in mind the future occurrence of a Nankai Trough Earthquake and associated giant tsunami, certain areas with higher possibilities of disaster damage were selected for extensive study: the wide Shikoku-Kinki area on the Pacific coast[3], Kyushu[4], and West Japan on the coast of the Japan Sea[5]. This report describes the results of the propagation measurement conducted moving around different areas. The study included up and down-link margin measurement of satellite links in a stationary state, the results of which are also described.

2 WINDS vehicle earth station

The specifications of the vehicle earth station are listed in Table 1, and its appearance is shown in Fig. 1. The vehicle earth station consists of such elements as a radome antenna (cassegrain antenna with a diameter of 65 cm), a 20W-class high power amplifier (HPA), a 3-axis gimbal mechanism, modulator and demodulator. As shown in

Table 1 Specifications of the vehicle earth station

Tx frequency	27.5-28.6 GHz
Rx frequency	17.7-18.8 GHz 18.9 GHz (for receiving beacon)
Polarized wave	Linearly-polarized wave (V/H)
SSPA output	20 W
EIRP	55.5 dBW
G/T	16.0 dB/K
Antenna	Cassegrain antenna Diameter: 65 cm
Antenna driving range	El: 20-90 deg Az: endless rotation X-El: ± 15 deg
Tracking accuracy	<± 0.2 deg
Data rate	Regenerative mode Tx: 1.5, 6, 24, 51 Mbps Rx: 155 Mbps
User interface	Ethernet (1000 base-T)
Power generation capacity	≧ 2.8 kVA

Fig. 1 Appearance of vehicle earth station

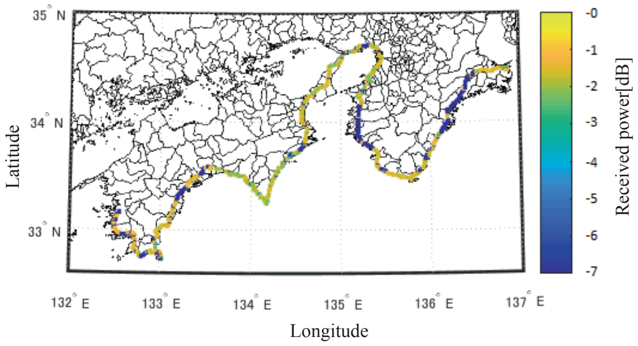

Fig. 2 The route for measurement in Shikoku-Kinki area (Beacon signal power)

Fig. 1, the earth station is mounted on a van.

The antenna system mounted on the vehicle earth station is capable of automatically detecting and tracking the satellite, for which exact positioning of the earth station (determined by GPS signal) and Beacon signal level (global beam from the satellite) are used. These features enable the vehicle earth station to link with the satellite even while it is running. The Beacon signal in this context means the residual carriers of network monitoring information (telemetry radios for Mission Planner). Other features such as HD cameras and wireless LAN access points are also installed in the earth station as an effective function for emergency / disaster.

3 Propagation measurement experiment

3.1 Experimental method

In this experiment, the vehicle earth station on the move received an 18.9 GHz Beacon signal (sent from WINDS) for evaluation of received signal power. The

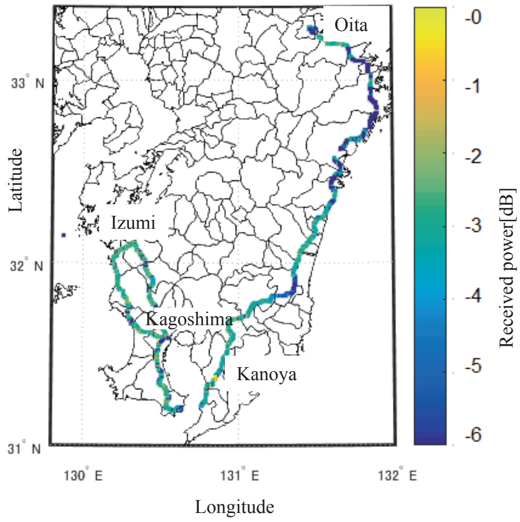

Fig. 3 The route for measurement in Kyushu area (Beacon signal power)

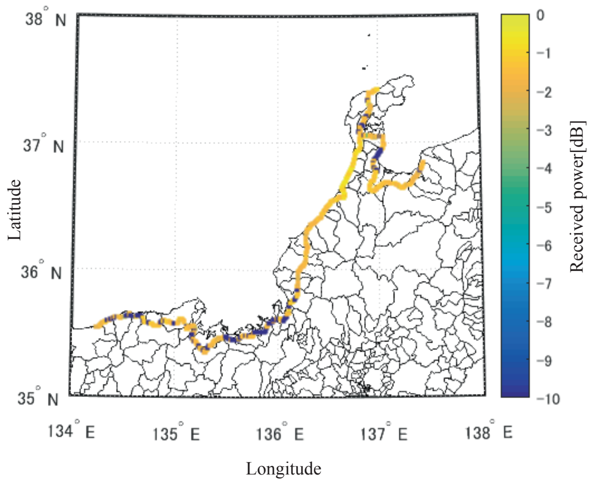

Fig. 4 The route for measurement in West Japan facing the Sea of Japan (Beacon signal power)

Beacon signal was evaluated using a spectrum analyzer at every 100 ms for the peak received power and frequency. On the expressway, the maximum speed of the vehicle was 100 km/h.

The routes selected for measurement include those envisaged to be most vulnerable to a Nankai Trough Earthquake and subsequent tsunami: the coastal roads of the Shikoku and Kinki areas facing the Pacific Ocean (Fig. 2), coastal roads from Oita to Kagoshima (Fig. 3), and coastal roads facing the Japan Sea from Shimane to Toyama (Fig. 4). Measurements were taken while the car was on the move. Each plot of these figures is color coded illustrating the power of the Beacon signal (the sections plotted in blue indicate lowered intensity due to shadowing or other factors). Note that the signal intensity was normalized

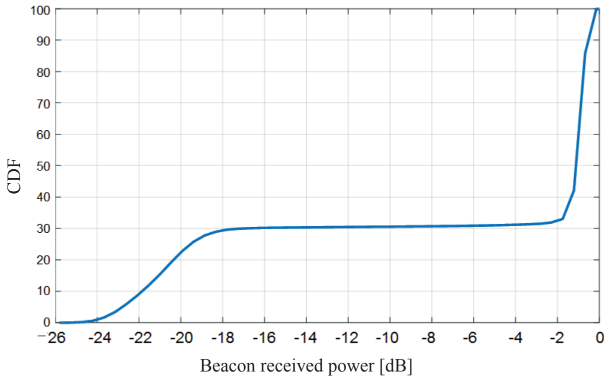

Fig. 5 CDF of Beacon received power: Shikoku-Kinki area

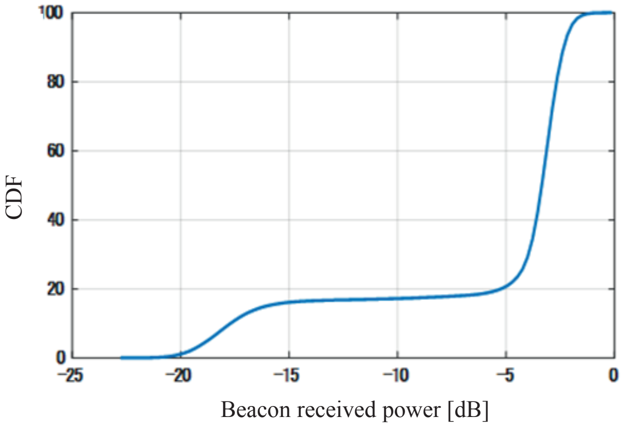

Fig. 6 CDF of Beacon received power: Kyushu area

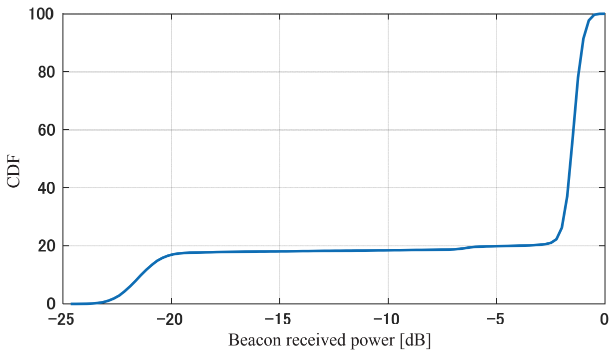

Fig. 7 CDF of Beacon received power: West Japan along the coast of Sea of Japan

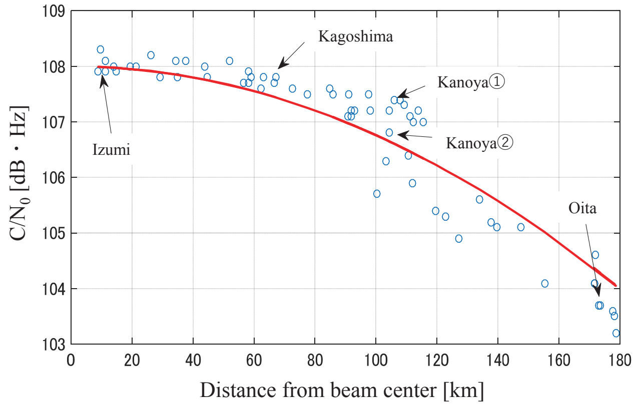

Fig. 8 Results of received C/N_0 measurement: Kyushu beam

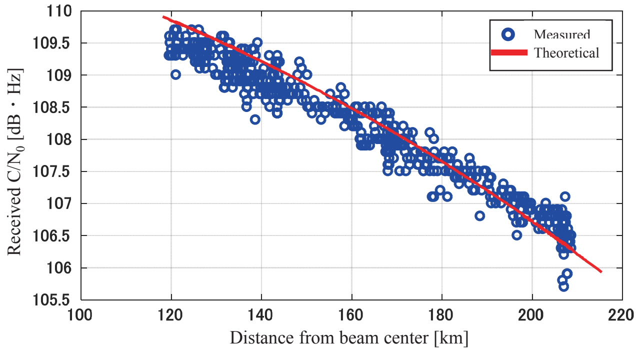

Fig. 9 Results of received C/N_0 measurement: MBA Chubu beam

using the maximum value in each measurement.

3.2 Results from measurements

The cumulative distribution function (CDF) of Beacon received power was calculated for three areas - Shikoku-Kinki, Kyushu, and West Japan along the coast of the Japan Sea. These results are shown in Fig. 5 to Fig. 7. From these figures, variation of the Beacon signal power in a line of site environment is the range of about 2 dB. In non-line of site environments, the signal power attenuated by -18 to -20 dB, down to below the noise floor level. Note that the data obtained in the Kyushu area shows larger variation of about 5 dB in the line of site environment. The cause is due to heavy rainfall during the measurement. The sections plotted in dark blue in Fig. 2 to Fig. 4 indicate that the earth station failed to capture the satellite signal. Overall, the ratio of the sections with a line of site environment (i.e. direct capturing of the satellite) over the entire length covered by the experiment was about 70% in the Shikoku-Kinki area, and about 80% in Kyushu and at the coast of the Sea of Japan in West Japan. The main factors causing poor visibility include utility poles, road signposts, buildings near the road, cliffs, tunnels, legs of railroad bridges, and trees along the road. Among them, tunnels were the most dominant factor. The experiment also proved the feasibility of satellite capturing while the earth station is on the move at high speed - 100 km/h on an expressway.

Figure 8 shows the plot of received C/N_0 (TDMA reference burst signal of a regenerative relay circuit originally sent from the Kyushu beam of the MBA [multi-beam antenna]) against the distance from the beam center. Two points in this figure, Kanoya① and ②, were measured at the same location on different days: the difference between

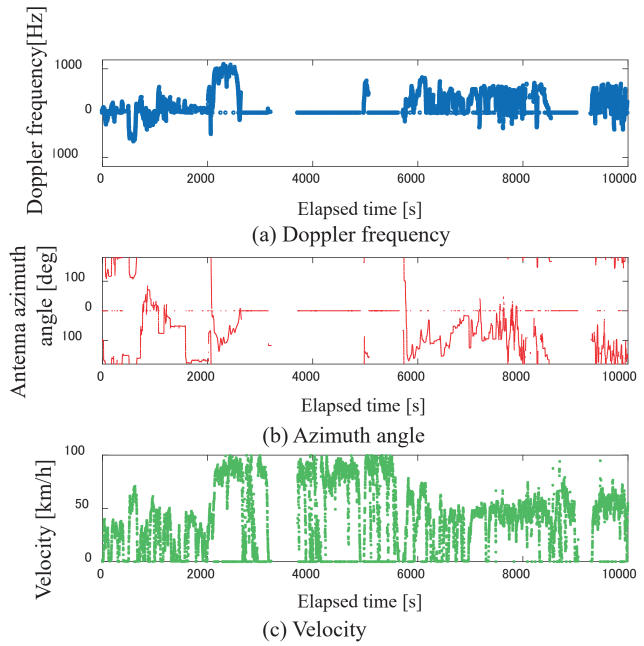

Fig. 10 Measured data obtained in the sections between Uwajima and Kochi

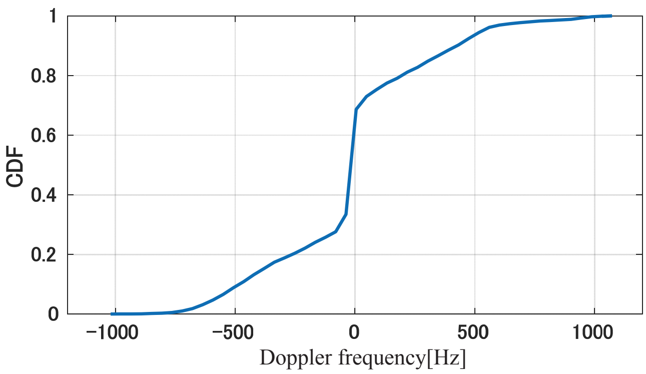

Fig. 11 CDF of Doppler frequency

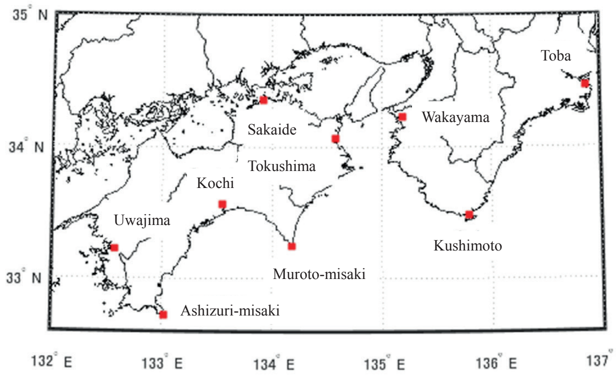

Fig. 12 Measurement points used in the data propagation experiment

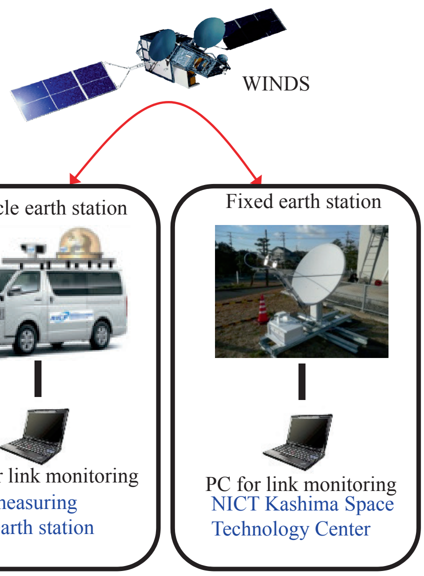

Fig. 13 Network configuration used in the data propagation experiment

the two is that Kanoya② is lower by about 1.5 dB as compared to Kanoya①. The cause is due to rainfall. Measured values showed good agreement with theoretical calculations (the red curve in the figure) with a standard deviation of 0.48 dB. Figure 9 shows received C/N_0 sent from the Chubu beam of the MBA (while measurements were taken in West Japan along the coast of the Sea of Japan) against the distance from the beam center. The measured values also showed good agreement with theoretical calculations with their deviation falling within ±1 dB.

The three plots in Fig. 10 show the measured data obtained in the section connecting Uwajima and Kochi. The vertical axes of these plots represent: (a) Doppler frequency, (b) azimuth angle of the mounted antenna, and (c) moving velocity of the vehicle earth station. In view of the fact that the satellite is located directly south of the vehicle earth station, Doppler frequency is expected to show positive values if the vehicle earth station moves toward south, and negative value if it moves toward north. The experiment demonstrated that this relation holds indeed. Figure 11 shows CDF of Doppler frequency measured along the whole extent of the Shikoku-Kinki area route. The maximum Doppler frequency in this area was 1,094 Hz.

Doppler frequency f_d is defined as:

$$f_d = \frac{v\cos\theta}{\lambda} \tag{1}$$

Where, v represents the moving velocity[m/s], θ represents the incident angle of radio waves relative to the traveling direction, and λ the wavelength [m]. By substituting the following three values into equation (1) — Beacon signal central frequency 18.9 GHz, antenna elevation angle 41.3°, and moving velocity 100 km — we get the maximum

Doppler frequency 1,154 Hz, which proved good agreement between the measured value and theoretical value.

4 Propagation measurement experiment

4.1. Data propagation experiment

UDP communication experiments were conducted in a stationary state (i.e. the vehicle earth station was not moving) at nine locations in the Kinki-Shikoku area which are shown Fig. 12.

The experiment-based UDP link connecting two stations is shown in Fig. 13. The vehicle earth station and a fixed earth station (NICT Kashima Space Technology Center, Kashima city) communicate through the satellite. The objective of this experiment was to evaluate the link margin of the up- and down-link through observation of the level of packet error occurrence using jperf[6].

The data propagation experiment used the MBA in regenerative 24 Mbps mode. The Chu-Shikoku beam was used in the experiments conducted in Uwajima, Ashizuri-Misaki, and Kochi, and the Kinki beam was used in other areas. For these two beams' comparison, both beams were used in the Kochi experiment.

4.2 Results from measurements

As the previous stage for the link margin measurement, the satellite's antenna gain was calculated. The antenna gain information is published only for the irradiation point and irradiation range[1]. The gain values at each measurement point are not available. To obtain the gain value at the measurement point, Az and El of the irradiation point (as viewed from the satellite) and the observation point are first calculated, and elongation between the two points is calculated. The next step is to calculate the reduction of gain at the measurement points away from the center of the antenna beam, which can be obtained mathematically from the knowledge that the shape of the central part of the antenna beam can be approximated by an axis symmetrical parabola using 3 dB beam width. Antenna gain at an measurement point can be evaluated from the irradiation point gain and the gain reduction value.

The link margin was obtained by designing the link budget using antenna gain and other parameters. Table 2 summarizes the results of the link margin measurements (up-link and down-link) at each measurement point. The figures shown in red in the table indicate plus margin. All the margin values measured in 24 Mbps mode are positive: on average, measured values are higher than the theoretical predictive values by 2.5 dB at up-link, and by 5.8 dB at down-link.

In the measurements conducted in Kochi, two different beams were used for comparison: the Chu-Shikoku beam (Kochi1) and the Kinki beam (Kochi2). It is interesting to note that deviations between measured and forecast values are reversed between Kochi1 and Kochi2, and a relatively large deviation was observed in Ashizuri-misaki. These findings can be interpreted to indicate that the center of the Chu-Shikoku beam is shifted to the south-east direc-

Table 2 Results from link margin measurement (Shikoku-Kinki area)

Measurement point		Uwajima	Ashizuri-misaki	Kochi 1	Sakaide	Kochi 2	Muroto-misaki	Tokushima	Wakayama	Kushimoto	Toba
Beam		Chu-Shikoku beam			Kinki beam						
Beam center and measurement point elongation [deg]		0.1395	0.2209	0.2073	0.1392	0.2354	0.1973	0.0695	0.0434	0.1634	0.2783
Up-link	Antenna gain [dBi] at measurement point	47.9	44.4	45.1	46.6	42.2	443.0	8.4	48.8	45.7	39.5
	Link margin [dB] (predictive)	7.04	3.55	4.24	5.62	1.25	3.35	7.44	7.84	4.75	-1.46
	Link margin [dB] (measured)	8.9	6.8	3.8	9.7	4.5	7.3	10.5	8.8	7.6	1.9
	Deviation (measured - predictive)	1.86	3.25	-0.44	4.08	3.25	3.95	3.06	0.96	2.85	3.36
Down-link	Antenna gain [dBi] at measurement point	46.4	45.0	45.3	47.1	45.2	46.1	47.9	48.0	46.7	44.1
	Link margin [dB] (predictive)	6.80	5.42	5.71	7.49	5.61	6.51	8.30	8.40	7.11	4.50
	Link margin [dB] (measured)	12.6	10.6	10.7	13.0	12.2	13.1	14.3	14.4	13.0	10.5
	Deviation (measured - predictive)	5.80	5.18	4.99	5.51	6.59	6.59	6.00	6.00	5.89	6.00

tion. The shift to the south-east direction was already reported from the analysis of initial-checkout[7], but the magnitude fell well within the required specifications. The shift is assumed to have grown larger with time. By the same token, the center of the Kinki beam has presumably shifted to the south-west direction from its nominal position. This estimation is derived from the observation that the deviation between measured and forecast values is found greater in the Shikoku measurement points than in the Kinki area.

Table 3 summarizes the data obtained in the Kyushu area, and Table 4 shows those obtained in West Japan along the coast of the Sea of Japan. The measured values at all points in these two areas also showed that the link margins are positive values. These data confirm the feasibility of 24 Mbps mode communication.

Table 3 Results from link margin measurement (Kyushu area)

Measurement point		Shikoku Chuo	Beppu	Beppu	Hyuga	Miyazaki	Kanoya	Yamakawa	Ichiki Kushikino	Izumi
Beam		Chu-Shikoku beam			Kyushu					
Beam center and measurement point elongation [deg]		0.1983	0.1635	0.2590	0.2044	0.1597	0.1262	0.1339	0.0694	0.0143
Up-link	Antenna gain [dBi] at measurement point	45.4	47.0	40.7	43.8	45.7	46.9	46.6	48.2	48.8
	Link margin [dB] (predictive)	4.46	6.06	-0.20	2.91	4.82	6.02	5.73	7.32	7.91
	Link margin [dB] (measured)	5.8	6.8	0.3	3.1	5.8	5.7	7.2	9.3	9.3
	Deviation (measured - predictive)	1.34	0.74	0.5	0.19	0.98	-0.32	1.47	1.98	1.39
Down-link	Antenna gain [dBi] at measurement point	45.4	46.0	44.4	45.7	46.5	47.0	46.9	47.6	47.8
	Link margin [dB] (predictive)	6.34	6.94	5.34	6.66	7.47	7.97	7.87	8.56	8.76
	Link margin [dB] (measured)	8.7	9.3	7.0	8.4	9.7	10.6	11.4	11.8	12.1
	Deviation (measured - predictive)	2.36	2.36	1.66	1.74	2.23	2.63	3.53	3.24	3.34

Table 4 Results from link margin measurement (West Japan - along the coast of Sea of Japan)

Measurement point		Tottori (Amarube)	Amano hashi-date	Kyou tango	Wakasa (Mikata goko)	Fukui	Kyou tango	Fukui	Kanazawa	Wajima (Senmaida)	Toyama
Beam		Kinki Beam			Chubu Beam						
Beam center and measurement point elongation [deg]		0.1614	0.161	0.1808	0.2185	0.2899	0.3273	0.2352	0.1598	0.2352	0.1435
Up-link	Antenna gain [dBi] at measurement point	45.8	45.8	44.9	43.2	38.6	37.7	46.9	47.7	44.1	48.2
	Link margin [dB] (predictive)	4.71	4.82	3.9	2.22	-2.4	-3.25	5.95	6.76	3.15	7.24
	Link margin [dB] (measured)	4.9	4.1	6	1.5	-0.8	-0.1	7	5.2	2.2	8.4
	Deviation (measured - predictive)	0.19	-0.72	2.1	-0.72	1.6	3.15	1.05	-1.56	-0.95	1.16
Down-link	Antenna gain [dBi] at measurement point	46.8	46.8	46.4	45.6	43.8	42.2	46	46.3	44.8	46.6
	Link margin [dB] (predictive)	7.02	7.63	7.2	6.44	4.6	3.1	6.9	7.21	5.7	7.5
	Link margin [dB] (measured)	11.4	11	8.6	9.9	5.3	2.9	7.4	10	7.7	7.1
	Deviation (measured - predictive)	4.38	3.37	1.4	3.46	0.7	-0.2	0.5	2.79	2	-0.4

5 Concluding remarks

Experiments with the mobile earth station were made to evaluate the propagation characteristics and up-link and down-link margin using the Ka-band satellite communication system. The data obtained from this experiment confirmed that the mobile earth station is able to capture the satellite above even it is moving at high speed. The ratio of the sections with a visible environment (i.e. the satellite can be captured in line of sight) over the entire length covered by the experiment was about 70% in the Shikoku-Kinki area, and about 80% in Kyushu and West Japan along the coast of the Sea of Japan. And then, tunnels were the dominant factor that hinders line-of-sight visibility.

Measurements of received C/N_0 of the reference burst signal from the MBA showed agreement between the measured and theoretical values (within ±1 dB).

Measurements of Doppler frequency also showed agreement with the theoretical value, confirming the validity of the link design approach that uses the maximum measured Doppler frequency corrected in consideration of the moving velocity of the earth station.

From the link margin values obtained, we can confirm the feasibility of 24 Mbps mode communication in all measured areas in the experiment. Although there are some elements that hinder satellite visibility, their effects are only transient except tunnels. Taking all factors into consideration, the results from all measured areas proved that satellite communication will be of great use at the time of a disaster.

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