Observation of the Terrestrial Radio Environment Using the Low Earth Orbit Satellite Constellation

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Abstract—**In recent years, spectrum sharing is one of the technologies to solve the depletion of spectrum resources due to the increasing demands for wireless communications. In spectrum sharing using a database, there is a method to use radio wave environmental data in order to improve the accuracy of interference calculation. When making the radio wave environmental data into statistics, it is necessary to measure the received power intensity at each position. However, this is difficult for a large area. Therefore, in this paper, the concept of a method to measure the received electric field intensity on the ground using a satellite constellation is proposed and examined.**

I. Introduction

In recent years, due to the increasing demand for wireless communications, the depletion of spectrum resources has become a problem. As a solution to this problem, spectrum sharing technology is attracting attention. In particular, dynamic spectrum access is a technology in which multiple systems use one frequency band by dividing time and space. This makes it possible to effectively use free spectrum resources. At present, it is being examined, tested, implemented, and put into practical use in countries around the world [1],[2],[3]. In dynamic spectrum access, there are existing systems with the highest priority and secondary systems that can use frequencies only in the temporal and spatial areas not used by existing systems. The secondary systems must not cause radio interference to existing systems and require advanced interference control. There are two main types of control methods to prevent interference with existing systems: the sensing method and the database method [4].

In the database method assumed in this paper, the primary system registers the utilization information in the database, performs interference calculation based on the information, and the secondary system uses the vacant resources in time and space that are available for secondary use. When the secondary system is a mobile station, accumulated interference occurs due to simultaneous radiation of multiple radio stations, and the interference power increases. Therefore, there is a concern that unexpected interference may occur and the utilization efficiency of spectrum resources may decrease due to excessive radio wave stop. Therefore, attention is paid to a method called radio map, which measures the received power value for each place and averages it for each two dimensional mesh to make statistics [5]. It is possible to improve the accuracy of interference calculation by utilizing this radio map and acquiring the radio wave environment unique to each place. However, at present, the measurement of a wide range is difficult because the measurement of the radio map is done by hand. Furthermore, it is also possible to contribute to the accuracy improvement of interference calculation by measuring the position of the radio wave source and the transmission power in real time.

The authors have proposed a system model for acquiring terrestrial radio wave environments from space far above the ground by utilizing satellite constellation in order to measure a wide range in a short time, and clarified the spatial resolution [6]. By using the proposed method, it was shown that the terrestrial radio signal strength could be observed stably and with high accuracy in comparison with the case in which the terrestrial radio signal strength was observed only by a single satellite. The spatial resolution when the beam was irradiated toward the ground from the satellite was clarified by simulation. In this paper, the proposed method is analyzed in detail, and the effectiveness of the proposed method is shown more clearly.

II. Proposed System Model

This section describes a system model and a proposed method for remote sensing of terrestrial radio signal strength from a satellite.

The system model is shown in Fig. 1. This system model consists of the combination of two proposed methods, i.e., the measurement method and the estimation method. As a premise, it is assumed that the satellites to be used are multiple satellites orbiting in low Earth orbit at an altitude of 300 [km] and constitute a low Earth orbit satellite constellation. Each satellite is equipped with an antenna that generates an ideal single beam with high gain, and the beam direction and reception time can be adjusted arbitrarily.

In a low-Earth orbit satellite such as the one assumed in this paper, the beam irradiated from the satellite does not spread on the ground surface and is directed to a specific narrow range. Even if the beam width is widened by reducing the size of the antenna, the resolution can be increased by narrowing the coverage range on the ground surface. Therefore, it is possible to reduce the size and cost of the antenna mounted on the satellite, which leads to the launching of many low-cost satellites. In addition, in a constellation, simultaneous observation by multiple satellites becomes possible, and the degree of freedom in measurement increases.

A. Proposed measurement method

As for the beam irradiation method, multiple satellites within the range of visibility from a certain ground point are used from among the satellites constituting the constellation. The beams are simultaneously directed to the same point from these satellites and the received power values are measured by each satellite. The received power values measured by each satellite is converted from logarithmic values to true values and then averaged. The averaged values are used as the received power value measured by the satellites and used to estimate the terrestrial radio signal strength. As a result, even if there is interference from outside the beam coverage, the effect can be suppressed. In addition, when only one satellite is used, the measured value varies due to fading, etc. Therefore, by using this proposed measurement method, beams can be irradiated from multiple directions, and improvement of measurement accuracy and stabilization of accuracy can be realized by space diversity.

B. Proposed estimation method

The received power values measured by the satellite does not become the terrestrial radio signal strength as it is. For the estimation, two methods were examined: the method using the free-space path loss and the method using the anchor.

First, a method using free-space path loss is described. The attenuation between the satellite and the ground is estimated by free-space path loss by distance. Since the distance from the altitude of the orbit around the satellite to the ground is known, the free-space path loss is calculated based on the distance. The antenna gain by the beam generated by the satellite is subtracted from the propagation attenuation value. This is used as a correction value, and the averaged received power value by the measurement method proposed in the preceding paragraph is added to it to estimate the terrestrial radio signal strength.

Second, an anchor, which is a transmission point whose transmission power and position are known, is separately arranged. A beam is generated from the satellite to the anchor in advance, and the propagation attenuation of the propagation path is measured. The transmission power of the anchor is subtracted from the measured value when the beam is directed at the anchor. This is used as a correction value, and the averaged received power value by the measurement method proposed in the preceding paragraph, as in the case of using free-space path loss, is added to it to estimate the terrestrial radio signal strength.

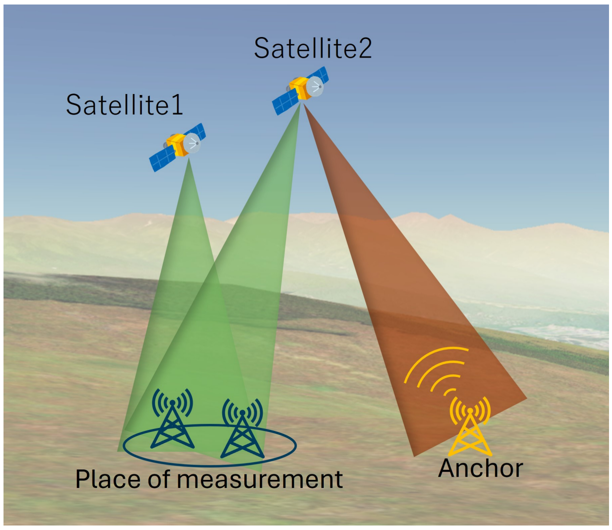

Fig. 1. Proposed system model

III. Simulation Overview

Understanding of the beam coverage and the estimation accuracy of the proposed estimation method were evaluated by the ray tracing simulation. The outline of the simulation is shown in Fig. 2, and the specifications are shown in Table I. The radio wave propagation condition was analyzed by setting the simulation range around Maeyama, Saku City, Nagano by WirelessInSite 3.4.4.12. In this paper, in order to reduce the calculation amount of the simulation software, the transmission and reception are reversed by utilizing the reversibility of the radio wave propagation. That is, originally, the terrestrial terminals become the radio wave source, and the satellite receives the radio wave. However, in this simulation, the satellite becomes the transmitter and transmits the radio wave toward the ground, and then the terrestrial terminals receive the radio wave from the satellite. As for the measured value, the received power value obtained by each terrestrial terminal is used as the received power value of the satellite when each terrestrial terminal transmits. The following estimated value is the value calculated by estimating the transmission power of the terrestrial terminals using the proposed system in the state before the transmission and reception are reversed.

The assumed satellite constellation orbits 300 [km] above the ground, and the antenna generates an ideal single beam with a half-power beamwidth of 5 degrees and a maximum gain of 30 [dBi]. Two satellites are placed, and all satellites generate beams toward one point. Satellite1 is placed directly above the beam irradiation center, and this satellite generates beams vertically from itself. Satellite2 is placed 5 [km] north of satellite1, and the beam is tilted 0.955 degrees south. This causes the beam to face the beam irradiation center. Since transmission and reception are reversed, the radio wave

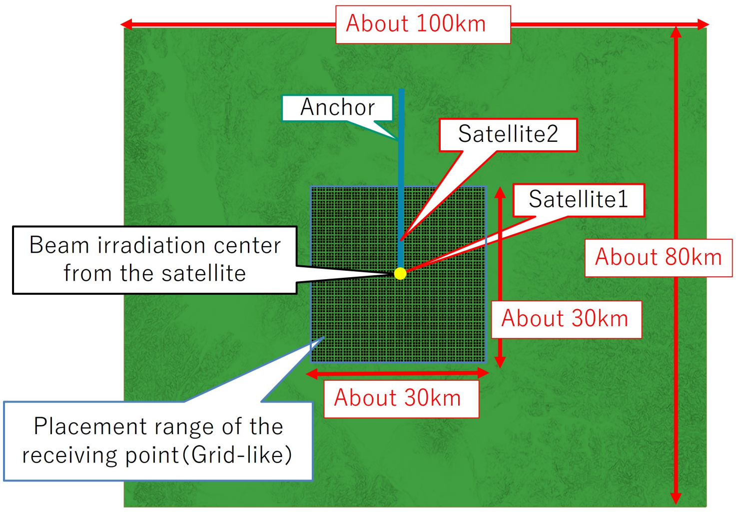

Fig. 2. Simulation Overview

TABLE I
SIMULATION DATA

Item	Value
Receiver(Terrestrial terminals)	
Center frequency	3650 [MHz] (3.7 [GHz] band)
Bbandwidth	100 [MHz]
Directivity	Omni-directional
Arrangement	500 [m] grid
Transmitter(Satellite)	
Center frequency	3650 [MHz] (3.7GHz band)
Bbandwidth	100 [MHz]
Transmit power	0 [dBm]
Directivity	Ideal single beam
Antenna maximum gain	30 [dBi]
Half-Power beamwidth	5 degrees
Altitude	300 [km]
Polarization	Left-hand circular
Channel Model	
Propagation model	X3D
Number of reflections	3
Number of transmissions	0
Number of diffractions	1

from the satellite uses a Left-hand circular polarized wave. As for the terrestrial receivers, the receivers are uniformly placed at 500 [m] intervals within a range of about 30 [km] $\times$ about 30 [km] square around the irradiation point of the beam. In this paper, in order to grasp the beam coverage and clarify the estimation accuracy for each position, there are no multiple transmitters and there is no interference. For each receiver, measurement using averaging and estimation by the two methods shown in the proposed method are performed. In order to perform estimation using anchors, anchors are placed linearly at 500 [m] intervals north of the beam irradiation center as shown in Fig. 2.

IV. Simulation Result

This section presents the simulation results separately for the proposed measurement method and the proposed estimation method.

A. Proposed measurement method

Fig. 3 and Fig. 4 show the absolute value of the difference between the estimated value by the measurement method and the correct value when the estimation method using free-space propagation attenuation is applied. The correct value is the value actually transmitted by the transmitter. Fig. 3 shows the result of applying the proposed estimation method of taking the average value of two satellites for each receiver. Fig. 4 shows the result of using the value measured by one satellite for each receiver. Each point of the heat map is the position of the receiver placed on the ground, and the error between the actual transmission power and the estimated value is shown in color. The value is a positive number because the absolute value of the error is taken in this heat map. The darker the blue, the smaller the error, and the darker the red, the larger the error. The range is the smallest at the deepest blue, with an error of 0 [dB], and the largest at the deepest red, with an error of 20 [dB]. Comparing these figures, when the average value of two satellites is taken, the points where the error is large are reduced, and the color changes relatively gently from the center to the periphery. This simulation is conducted in a place where the undulation of the landform is severe, but the change according to the landform is not observed.

Fig. 5 shows the relationship between the distance from the beam irradiation center and the estimation error. The error is plotted on the vertical axis and the distance from the beam irradiation center at each terrestrial receiver is plotted on the horizontal axis. This is not the absolute value of the difference from the correct value, but the value obtained by subtracting the correct value from the estimated value. Fig. 5 shows that the error increases as the distance from the beam irradiation center increases for both the case where the average of two satellites is taken and the case where only a single satellite is taken. However, the magnitude of the error is still less than 14 [dB] even at a distance of about 20000 [m]. It is also shown that the error fluctuation is suppressed by taking the average of two satellites.

From these, the spread of the error in generating the beam with the directivity from the satellite which is 300 [km] up to the ground was able to be confirmed. Since the change of the error by the undulation of the landform is not observed, it is considered that the effect of the landform on the error is slight. From the heat map of Fig. 3 and Fig. 4 and the graph of Fig. 5, the fluctuation of the error is suppressed in the proposed measuring method. Therefore, it is possible to improve the stability and accuracy of the measured value by measuring by multiple satellites simultaneously.

B. Proposed estimation method

Fig. 6 shows the heat map of the estimation method using the anchor. The heat map of Fig. 6 was prepared under the

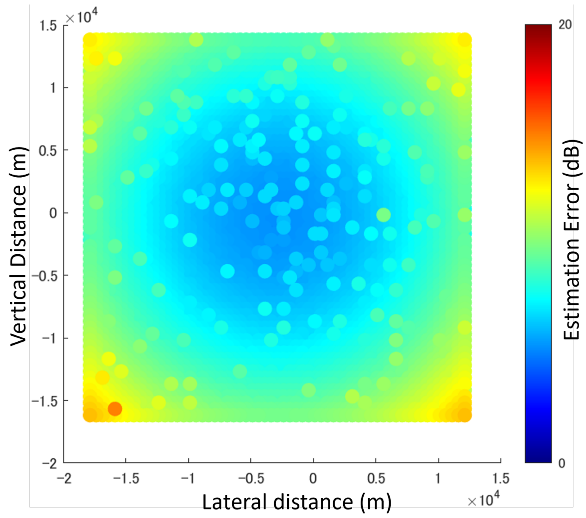

Fig. 3. Heat map of estimation error when using the average value of two satellites(Free-Space Path Loss)

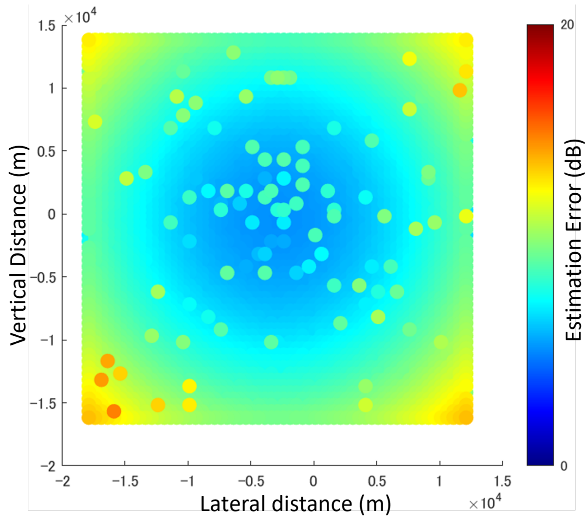

Fig. 4. Heat Map of Estimation Error Using Received Power Value of Only One Satellite(Free-Space Path Loss)

same conditions as Fig. 3 except for the estimation method. In this fig. 6, the anchor was placed at the beam irradiation center of the satellite. In other words, since the anchor is placed at the position where the measurement is desired, the received power on the ground surface is estimated with accurate propagation attenuation information obtained. Comparing Fig. 6 with Fig. 3, it can be seen that the error of the estimation method using anchors is overwhelmingly small.

In Fig. 7, the distribution of the error due to the distance from the center of the beam irradiation is shown for each estimation method. As for the estimation using the anchor, as in Fig. 6, the anchor position is at the center of the beam irradiation. This shows that the estimation using the anchor has about 5 [dB] less error than the estimation using the free-space

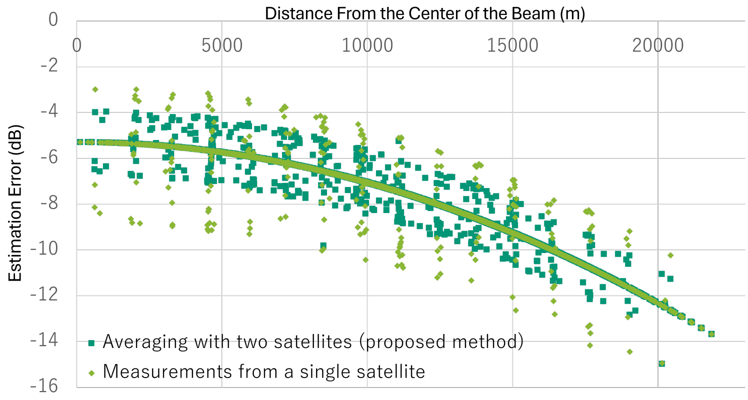

Fig. 5. Relationship between the distance from the center of the beam and the estimation error according to the number of satellites used

path loss.

Fig. 8 shows the change in the heat map when the position of the anchor is moved away from the beam irradiation center. As shown in Fig. 2, multiple anchors are arranged in a straight line toward the north from the beam irradiation center. Therefore, this time, the heat map was created by selecting only one ground reception point to be used as an anchor at every 1500m toward the north from the beam center. From these figures, it can be seen that the position where the error is small spreads outward as the distance from the beam irradiation center increases, and it changes outward in a doughnut shape when the distance exceeds 6000 [m].

As a result, in the estimation method using the anchor, the accuracy was greatly improved in the estimation in the most ideal condition in which the anchor was placed at the position to be measured, compared with the estimation method using the free-space path loss, and it was possible to confirm the distribution change of the error by the position of the anchor from Fig. 8.

V. Summary

A system model and estimation method for grasping the terrestrial radio wave environment from the satellite are proposed. Visualization of the beam coverage for each estimation method and accuracy analysis of the measurement method are carried out by simulation. It is shown that the proposed measurement method can suppress the fluctuation of the error in comparison with the case in which one satellite is used, and that stable and high-precise measurement is possible. Comparison between the proposed 2 kinds of estimation methods and the change of the error by the position of the anchor are shown. In the future, analysis in the case in which multiple terrestrial terminals are simultaneously operated and narrowing of the coverage and high-precision are aimed by combining multiple beams.

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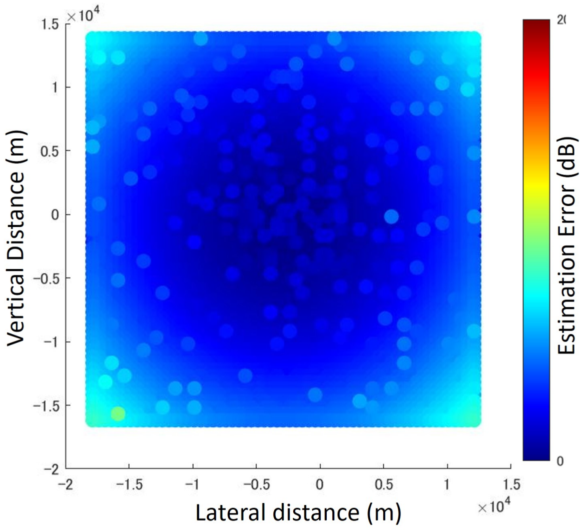

Fig. 6. Heat map of estimation error when using the average value of two satellites(Using an anchor)

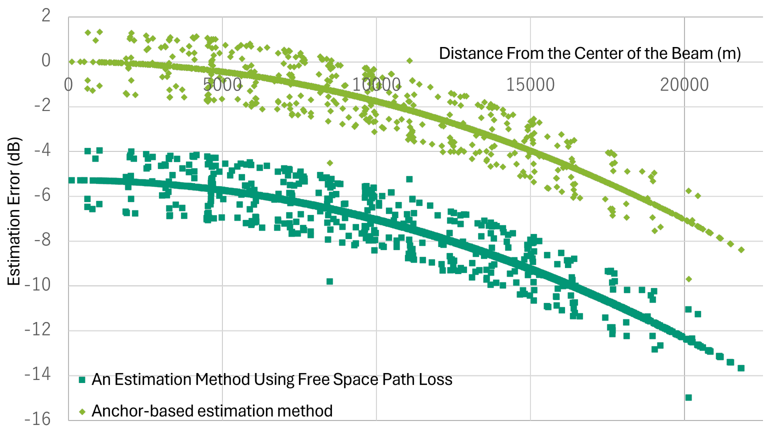

Fig. 7. Comparison of estimation methods for distance from center of the beam and estimation error

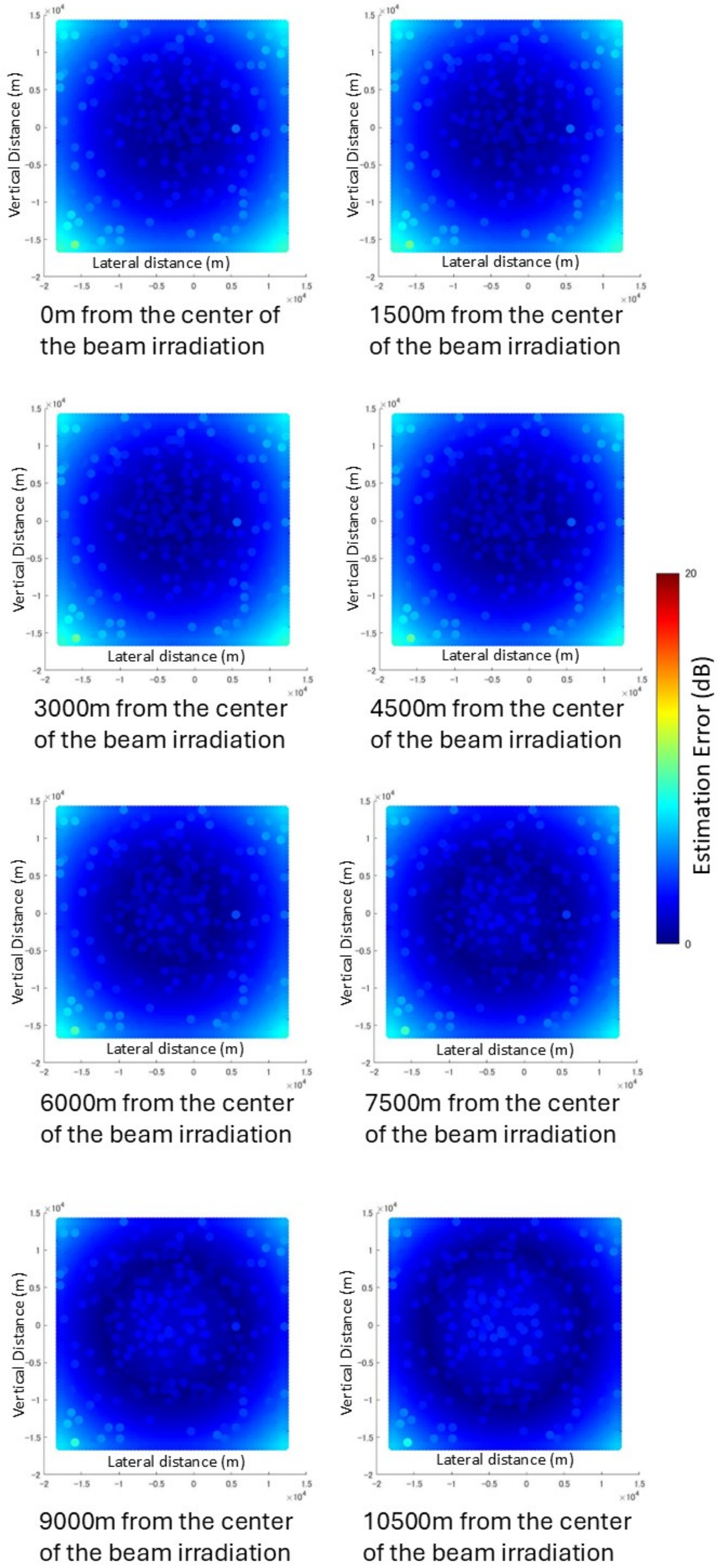

Fig. 8. Heat map changes when anchor position is moved

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