# Improvement of Terrestrial Radio Environment Measurement Methods Using Satellite Constellations


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***Abstract*—Spectrum sharing is one of the technologies to solve the depletion of frequency resources caused by the recent increase in the demand for wireless communications. In spectrum sharing using a database, there is a method to use the radio wave environmental data of each place in order to improve the accuracy of interference calculation. Since it is difficult to make the radio wave environmental data into statistics in a wide range, the authors proposed and examined a method to remotely measure the electric field intensity on the ground using a low Earth orbit (LEO) satellite. This method is divided into a measurement method and an estimation method. In this paper, we propose a new measurement method that enables high-precision measurement by suppressing the influence of interference. This improved measurement method has significantly reduced interference during measurement compared with the conventional method.**



***Index Terms*—Frequency Spectrum Sharing, Satellite Constellations, Low Earth Orbit, Remote Sensing, Wireless Communication.**


## I. Introduction

In recent years, demands for wireless communications have increased, and as many wireless systems are used, the depletion of frequency resources has become a problem. As a solution to this problem, spectrum sharing technology has attracted attention. In particular, dynamic spectrum access is a technology in which multiple systems use a single frequency band in separate time and space. This enables the effective use of unused frequency resources. In dynamic spectrum access, there are an existing system with the highest precedence and a secondary system that can use frequencies only in the temporal and spatial regions that are not used by the existing system. The secondary system must not interfere with the existing system, and advanced interference control and margins are required. The mechanism of dynamic spectrum access is currently being studied, implemented on a test basis, and put into practical use in countries around the world [1], [2], [3]. Systems that share frequencies are not limited to terrestrial wireless systems. Sharing of frequencies by the same transmitter, such as spectrum sharing between a user link and a feeder link of a high altitude relay system (HAPS) system, is also being studied [4]. Power control technology for satellite communications and terrestrial communications systems is also being studied [5]. In addition, spectrum sharing using blockchain technology to solve security problems is also being studied. [6].

There are two main methods for controlling the existing system to prevent interference: the sensing method and the database method [7]. In the database method assumed in this paper, the primary system registers usage information in the database, performs interference calculation based on the information, and the secondary system uses the available spatial and temporal resources available for secondary use. When the secondary system is a mobile station, cumulative interference occurs due to simultaneous radiation of multiple radio stations, and the interference power increases. Therefore, there is a concern that the utilization efficiency of frequency resources may decrease due to the occurrence of unexpected interference and excessive radio outage depending on the number of radio stations assumed at the time of interference calculation. Therefore, a radio map, which measures the received power value for each location and averages it for each two dimensional mesh, is attracting attention [8]. Utilizing this radio map to obtain the radio environment specific to each location is useful for improving the accuracy of interference calculation. However, at present, manual measurement is performed for the preparation of the radio map, and it is difficult to measure a wide range.

As described above, it is possible to make more effective use of limited frequency resources by investigating and monitoring the radio wave environment at each location on the earth's surface. In this research, we aimed to measure and estimate the transmission power of communication devices on the surface of the earth from space using satellites. Since satellites are used, there is an advantage that a wide range can be measured. In addition, since it is not only for spectrum sharing, it can be applied to any system that uses radio waves regardless of a specific radio system. In addition, by measuring not only the position of the radio source but also the transmission power, the effective use of this technique expands. For example, in spectrum sharing, by measuring the position of radio sources and the transmission power in real time, it becomes possible to estimate the geographical spread and strength of radio waves, which can contribute to further improvement in the calculation accuracy of the secondary usable area. In addition to spectrum sharing, it can be used to detect excessive transmission power and detect illegal radio stations.

Regarding the acquisition of the radio wave environment on the ground surface, beam coverage in the VHF band has been studied in the design of satellites for Automatic Identification System (AIS) used for navigation of ships [9]. However, the authors have only been working on the measurement and estimation of the transmission power from satellites to terrestrial transmitters [10].

The authors proposed a system model for acquiring the terrestrial radio environment from the space far above the ground by utilizing a satellite constellation in order to measure a wide range in a short time, and clarified the spatial resolution and the usefulness of the proposed measurement method [10]. However, when a transmitter other than the estimation target is present in the vicinity, a large error occurs in the transmission power estimation using a satellite. In this paper, we propose an improved measurement method that uses a new satellite for interference reduction to suppress interference from a location other than the measurement target and enable more accurate measurement. We also evaluate it by simulation and show that the proposed method can perform measurement while suppressing interference.

## II. Proposed System Model

This paper describes a system model and a proposed method for remote sensing of the transmission power of a ground terminal 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 LEO at an altitude of 300 [km] and constitute a LEO 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 LEO satellite such as the one assumed in this paper, the beam irradiated from the satellite does not spread relatively wide on the Earth's surface compared to a mid-Earth orbit satellite or a geostationary orbit satellite, and is directed to a specific narrow range. This makes it possible to reduce the size and cost of the antenna mounted on the satellite, leading to the launch of many low-cost satellites. In addition, the constellation enables simultaneous observation by multiple satellites, increasing the degree of freedom in measurement.

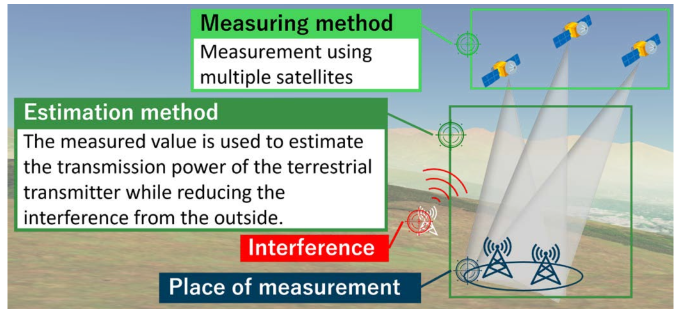


Fig. 1. Proposed System Model

This paper describes only the improved measurement method, not the estimation method.

### A. Proposed measurement method

The proposed measurement method is explained. An image is shown in Fig. 2. It is assumed that three or more satellites in the line-of-sight range can be used from a certain ground point, and that the position of the transmitter to be measured is known in advance. Only one of the satellites in the line-of-sight range behaves differently as an interference-reducing satellite. Hereinafter, this satellite is referred to as an interference-reducing satellite. There are a plurality of satellites other than the interference-reducing satellite in the line-of-sight range, which are hereinafter referred to as measuring satellites.

The measurement satellites simultaneously aim their beams in the direction of the transmitter to be measured, and all the satellites measure the received power. The received powers measured by all the measurement satellites are converted from logarithmic values to true values, added together, and averaged. The averaged value is used to estimate the transmission power of the measurement target. Thus, the beams can be irradiated from multiple directions. By using spatial diversity, the measurement accuracy can be improved and stabilized by reducing the influence of fading, etc., compared with the measurement using only one satellite. However, this alone is not sufficient to suppress interference from outside the measurement target.

Therefore, an interference reduction satellite is used. The interference reduction satellite moves the beam around the measurement target and measures the received power at any time. The flow of the reduction method is shown below.

1) Convert all the received power obtained during one round to the true value, add them together, and calculate the average, which is used as a numerical value for interference reduction (reduced value).
2) The average value of the received power of the measurement satellite described in the preceding paragraph is converted into the true value, which is used as the measured value.
3) Subtract mitigation from measured value

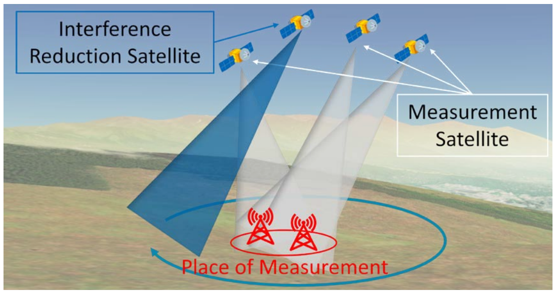


Fig. 2. Proposed Measurement Method Overview

4) If the result of subtraction is negative, the measured value is used without subtracting the reduced value.

Regarding (4), when the reduced value is larger than the measured value, it is considered that the interference is only in the beam direction of the interference reducing satellite, and the interference in the vicinity of the measurement target is slight, so that the interference from the periphery of the measurement target can be reduced evenly regardless of the direction of the interference source.

## III. Simulation Overview

The accuracy of the proposed method was evaluated by ray-tracing simulation. The outline of the simulation is shown in Fig. 3, and the specifications are shown in TableI. The simulation range was set around Maeyama, Saku City, Nagano prefecture using WirelessInSite3.4.4.12, and radio wave propagation conditions were analyzed.

The specifications of the on-board satellite antenna are shown in Table II. A phased array antenna with a maximum gain of 32.81 [dBi] was designed to be mounted on the satellite. Five satellites were placed 300 [km] above the ground. Of the five satellites, one interference reduction satellite was placed at the center, and the remaining four measurement satellites were placed 5 [km] apart from the interference reduction satellite in the east-west and north-south directions, respectively. The transmitter of the measurement target was placed directly below the interference reduction satellite. The transmission power was 0 [dBm]. A non-directional antenna was assumed. The transmitter as the interference source was placed at a radial interval of 1 [km] from the measurement target transmitter in the east-west and north-south directions. The specifications of the interference source were the same as those of the measurement target.

The beam direction of the satellite is explained. An image is shown in Fig. 4. The measuring satellites located on the east, west, north, and south sides of the interference mitigation satellite generate beams at an angle of 0.955 degrees toward the interference mitigation satellite, and direct the main lobe toward a point of the measurement target. The interference mitigation satellite generates beams by circling the measurement target directly below it at an angle of 1 degree from the vertical direction. During the circling, measurement is performed eight times at an angle of 45 degrees.

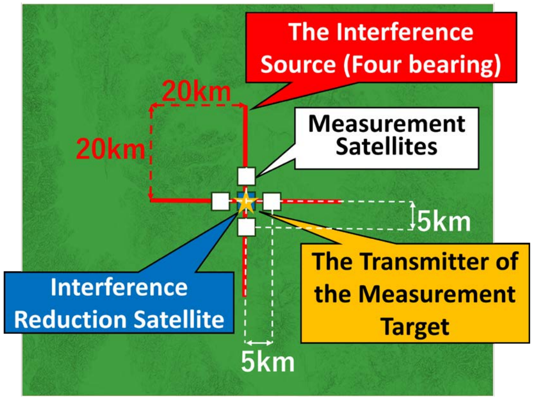


Fig. 3. Simulation Overview

TABLE I
Simulation data

| Parameter | Value |
|---|---|
| Receiver(Satellite) | |
| Center frequency | 7000 [MHz] |
| Bbandwidth | 100 [MHz] |
| Altitude | 300 [km] |
| Transmitter(Terrestrial terminals) | |
| Center frequency | 7000 [MHz] |
| Bbandwidth | 100 [MHz] |
| Transmit power | 0 [dBm] |
| Directivity | Non-directional |
| Channel Model | |
| Propagation model | X3D |
| Number of reflections | 3 |
| Number of transmissions | 0 |
| Number of diffractions | 1 |

In the ground transmitter, two points in total, a measurement target with one point and one of the interference sources arranged radially, transmit simultaneously. Therefore, the interference source is always one point, and the change by the position of the interference source was examined.

## IV. Simulation Result

Fig. 5 shows the change in the amount of interference depending on the position of the interference source. The horizontal axis represents the distance between the measurement target and the interference source, and the vertical axis represents the amount of interference. The amount of interference is the difference between the measurement results when there is interference and the reference value when only the measurement target transmits and there is no interference. Therefore, the closer the value is to 0, the more the effect of interference can be reduced. In addition, the interference sources are arranged in the east, west, north, and south directions in order to reduce the inherent fluctuation due to the direction. The average of the measurement results in the east, west, north, and south directions for each distance was used to create the graph. The measurement results when two points, the measurement target and the interference source 1 [km] in the east direction, transmit are obtained. The measurement results when two points, the measurement target

TABLE II
ANTENNA DATA

| Parameter | Value |
|---|---|
| Center frequency | 7000 [MHz] |
| Size | W: 1.44 [m] × D: 1.44 [m] |
| Element arrangement | URA |
| Number of elements | 1024(32×32) |
| Element spacing | 23 [mm] |
| Taper | Hamming |
| Maximum gain | 32.81 [dBi] |
| HPBW | 4.44° Az / 6.00° El |

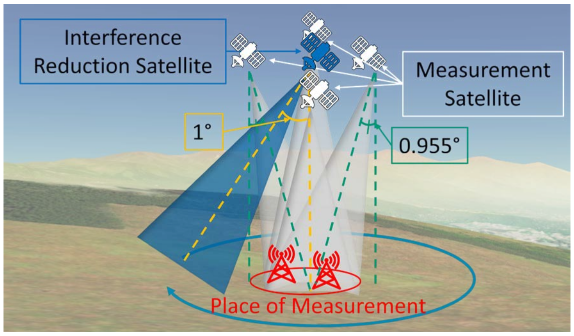


Fig. 4. Simulation Overview Image

and the interference source 1 [km] in the west direction, transmit are obtained. Similarly, the measurement results 1 [km] in the south direction and 1 [km] in the north direction are obtained. The average of the obtained four measurement results is plotted on the horizontal axis of the graph at 1 [km]. The conventional method shows the case where only four measurement satellites are used without using an interference reduction satellite, and the proposed method shows the case where one additional interference reduction satellite is used.

Fig. 5 shows that in the case of no mitigation (conventional method), there is interference of about 3 [dB] when the interference source is close, and it decreases as the interference source moves away. On the other hand, when the proposed method is applied, the interference is relatively reduced by about 2 [dB] when the interference source is close. It approaches 0 [dB] as the interference source moves away. When the distance exceeds 14 km, the interference is reduced too much, and the error becomes larger than in the case without reduction. It can be seen that the proposed method can reduce the interference particularly well when the interference source is close. The cause of this is considered to be that even if the interference source is far away and the effect is small, the reduction beam receives the radio wave from the measurement target and tries to cancel the interference more.

## V. SUMMARY

In this paper, we propose an improved measurement method that can reduce interference in a system model for understanding the radio wave environment on the ground from a satellite, and study the interference reduction effect by simulation. In the proposed measurement method, the interference reduction effect of about 2 [dB] is confirmed when the interference

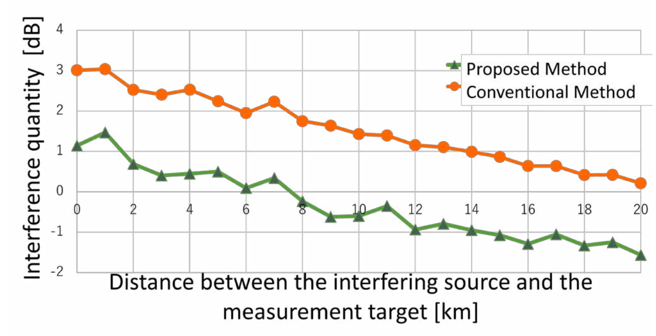


Fig. 5. Difference From the Standard Value (average in the east-west north-south direction)

source is relatively close to the measurement target, compared with the case where only the measurement satellite is used. In the future, we will study a method that can reduce errors even when the interference source is far away and a reduction processing method using flexible beam scanning.

## ACKNOWLEDGMENT


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