A study of antenna beam direction estimation for dynamic spectrum sharing

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Abstract: To realize dynamic spectrum sharing, it is necessary to avoid interference from the secondary system to the primary system. Technical information such as the position of the radio station and the antenna specification of the primary system are required to estimate interference to the primary system accurately, but these specifications are not generally disclosed. In this paper, we propose a method for estimating the antenna beam direction using only information on the received power at the radio wave sensors. Using the simulation data and the outdoor measurement data, the evaluation confirmed the effectiveness of the proposed method.

Keywords: antenna beam direction estimation, dynamic spectrum sharing, correlation

Classification: Antennas and Propagation

References

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1 Introduction

Finding new frequency resources has become an urgent issue due to the rapid increase in mobile communication traffic. Since many frequency bands are already allocated to various radio systems, dynamic spectrum sharing (DSS) schemes that realize frequency sharing between different systems have been studied [1]. DSS is a technology that avoids interference to the primary system, and makes it possible to allocate frequency bands to other systems at times and locations when the primary system has vacant bandwidth. In order to realize DSS, it is necessary to make an accurate estimation of the interference to the primary system. However, the technical information required for estimating the interference, such as the position of the radio station and the antenna specification of the primary system, are not generally disclosed in order to protect sensitive information, so developing a technique capable of estimating such information is important. Several position estimation methods are being studied [2], and an algorithm to estimate the position of radio stations using only the received power at radio wave sensors has been proposed [3]. However, a method for estimating the antenna beam direction from the received power at radio wave sensors has never before been proposed. Therefore, this paper proposes a method for estimating the antenna beam direction of a radio station solely from the received power at radio wave sensors. Using the simulation data made by the ray-tracing method, an evaluation confirmed that the proposed method can estimate the beam direction of the radio station correctly. The evaluation used measurement data obtained in a suburban area and it was demonstrated that the proposed method could estimate the beam direction of the radio station under an appropriate situation.

2 Estimation of antenna beam direction

The proposed method estimates the antenna beam direction using the correlation coefficient between the actual received power distribution, which is measured at radio wave sensors deployed in the field, and the estimated power distribution obtained by calculation. Figure 1 shows a flowchart of the proposed algorithm. This algorithm calculates the correlation coefficient $r(\theta_n)$ with the antenna beam direction $\theta_n$ varying in $360/N^\circ$ steps, and finds the direction $\theta_n$ that maximizes the value $r(\theta_n)$. Here, the correlation coefficient $r(\theta_n)$ is calculated by Eq. (1).

$$r(\theta_n) = \frac{\frac{1}{T} \sum_{t=1}^{T} \left( (P_{0,t} - \overline{P}_{0,t}) (P_{1,t}(\theta_n) - \overline{P}_{1,t}(\theta_n)) \right)}{\sqrt{\frac{1}{T} \sum_{t=1}^{T} \left( P_{0,t} - \overline{P}_{0,t} \right)^2} \sqrt{\frac{1}{T} \sum_{t=1}^{T} \left( P_{1,t}(\theta_n) - \overline{P}_{1,t}(\theta_n) \right)^2}}. \quad (1)$$

In Eq. (1), $T$ is the number of radio wave sensors, $P_{0,t}$ is the received power at the $t$-th radio wave sensor ($t = 1$ to $T$), and $P_{1,t}(\theta_n)$ is the estimated received power at the position of the $t$-th radio wave sensor assuming that the antenna beam direction of the radio station is $\theta_n$. $\overline{P}_{0,t}$ is the average power of $P_{0,t}$ and is calculated by $\sum_{t=1}^{T} P_{0,t}/T$. Also, $\overline{P}_{1,t}(\theta_n)$ is the average power of $P_{1,t}(\theta_n)$ with the antenna beam direction $\theta_n$ and is calculated by $\sum_{t=1}^{T} P_{1,t}(\theta_n)/T$. The received power at the radio wave sensors can be calculated from technical parameters such as exact positions, transmitting power, antenna beam pattern and direction of the radio station, and propagation loss between the radio station and the sensors. The received power can be estimated with...
a higher degree of precision if these parameters are accurate, and the correlation coefficient $r(\theta_n)$ value denoted by Eq. (1) becomes higher. In terms of the antenna beam direction, the correlation coefficient $r(\theta_n)$ attains its maximum value when the assumed beam direction is closest to the actual beam direction of the radio station. Therefore, the proposed method finds the beam direction $\theta_n$ that maximizes the correlation coefficient, and obtains the direction as a result of the estimated beam direction. In this paper, it was assumed that the position and transmitting power of the radio station were known. The antenna beam pattern for this evaluation was created based on document [4], and the beamwidth adopted a typical value used in cellular systems. This algorithm can be applied to various systems if the estimated received power is calculated using several beam patterns. In this paper, the azimuth beam direction estimation of the radio station was investigated in order to obtain the interference to the primary system targeting the horizontal direction. The proposed algorithm is effective for radio systems without beam tilt like those employed for inter-building communication. The beam tilt affects the interference calculation of such radio systems which provide services from radio stations on buildings to users on ground, so beam direction estimation in 3 dimensions including the vertical direction has become a future issue.

3 Evaluation of proposed algorithm

3.1 Evaluation using simulation data

We evaluated the proposed method in the case where there is a radio station in the center of a 4 km $\times$ 4 km suburban area. The antenna beam direction is expressed by a clockwise angle with north as 0°, and the antenna beam direction and the half-power beamwidth for the radio station were set to 0° and 60° respectively. In this evaluation, we assumed that the beam pattern of the radio station was known, and the antenna beam pattern denoted in [4] with a beamwidth of 60° was used for both the actual
radio station antenna and the antenna used in the beam direction estimation. The ray-tracing method was used in both the actual sensor received power calculation and the estimated received power calculation. Figures 2 (a) and (b) show the spatial power distribution of radio waves transmitted by the radio station. Figure 2 (a) is the case where a radio wave sensor is placed in the center of each mesh that divides the evaluation area into 50 m × 50 m squares, and the number of radio wave sensors is 6400. And Fig. 2 (b) is the case where the sensor interval is around 125 m, and the total number of radio wave sensors is 1000. Figure 2 (c) shows the graph with the assumed antenna beam direction as the horizontal axis and the correlation coefficient as the vertical axis. The correlation coefficient value became maximum when the assumed beam direction is 0° which is the same as the beam direction of the actual antenna in both cases where the interval between the sensors was 50 m (6400 sensors) and 125 m (1000 sensors).

![Fig. 2. Sensor received power and correlation coefficient](image)

3.2 Evaluation using measurement data
We evaluated the proposed method using the measurement data of two 2-GHz band LTE BSs (base stations) actually deployed in a suburban environment. The LTE BSs use directional antennas, and the antenna beam direction of radio station 1 and radio station 2 is 210° and 130°, respectively. We determined the evaluation area with a range of around 2 km × 2 km centered on radio station 1, and measured the received power by running a vehicle inside the evaluation area. Assuming that the radio wave sensors were arranged at intervals of about 100 m, the value measured at the closest position was assigned as the sensor received power. Figures 3 (a) and (c) show the sensor received power of radio station 1 and 2, respectively. The antenna beam direction of the LTE BSs was estimated using the sensor received power. Since the actual beam pattern and the beamwidth of the LTE BS antenna were not disclosed, we calculated a beam pattern with a beamwidth of 60° using the equation denoted in [4]. The ray-tracing method was used to calculate the estimated received power at radio wave sensors. The correlation coefficient of radio station 1 and 2 is presented in Figs. 3 (b) and (d) respectively, and became maximum when the estimated beam direction was 210° and 120° respectively. In Figs. 3 (a) and (c), the red arrow and the blue arrow indicate the actual beam direction, and the estimated beam direction obtained by the proposed method, respectively. There were no tall
buildings around radio station 1, so the propagation loss and the sensor receiving power were estimated with a high degree of accuracy by the ray-tracing method, and the beam direction could be estimated correctly. On the other hand, with regard to radio station 2, a beam direction estimation error occurred. It is considered that the main causes of the estimation error are that there were many buildings around radio station 2 and the propagation loss could not be estimated accurately, and that the placement of the radio wave sensors was biased to the north with respect to the position of radio station 2.

![Fig. 3. Evaluation using measured data](image)

### 4 Conclusion

In this paper, we proposed an algorithm for estimating the antenna beam direction of a radio station using the correlation coefficient between the calculated received power of the radio wave sensors and the received power of the actual sensors. The simulation results confirmed that the antenna beam direction can be estimated correctly. In addition, from the evaluation results using the measured data of the LTE BSs in a suburban area, the effectiveness of this algorithm was confirmed by showing that the direction can be estimated correctly under an appropriate situation.

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