社団法人 電子情報通信学会
THE INSTITUTE OF ELECTRONICS,
INFORMATION AND COMMUNICATION ENGINEERS

信学技報
TECHNICAL REPORT OF IEICE

マルチパス環境における電波放射源の位置推定に関する研究

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あらまし 近年，無線通信技術は幅広い分野に浸透している．一方，一般無線通信への混信，妨害となっている不法無線局が増加しており，その所在の探査，摘発が大きな課題となっている．本報告では，マルチパス環境において，MUSIC 法および 3 次元の鏡像法による解析に基づいた波源位置推定を行い，その有効性と精度について検討した結果を述べる．

キーワード MUSIC，アンテナアレー，マルチパス環境

Estimation of Electromagnetic Source Location in Multipath Environment

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Abstract A novel method to estimate the source location of electromagnetic (EM) waves in a complicated multipath urban areas is developed. The method is based on the multiple signal classification (MUSIC) algorithm and reciprocity of transmitting and receiving antennas. Results are shown to demonstrate the validity of the proposed method. This method can be applied to searching for the location of the illegal radio station in the urban areas.

Keyword MUSIC, Antenna arrays, Multipath urban areas

1. INTRODUCTION

Recently, the wireless communication achieve rapid development. On the other hand, the problem of illegal radio stations is becoming more and more serious, which causes damages to the sensitive electronics devices such as medical equipment and is also one of the causes of the radio interference and jamming to general radio communication systems and the public broadcast systems. Strict regulations against those illegal radio stations have been made and the Ministry of Public Management, Home Affairs, Posts and Telecommunications in Japan has taken some measures to monitor illegal radio stations by Detect Unlicensed Radio Station (DEURAS) system, which searches the location of the illegal sources by detecting the direction of radio emissions from illegal radio stations. In order to improve the accuracy of the location estimation, conventional techniques for the DOA estimation with antenna arrays, such as MUSIC algorithm [1], estimation of signal parameters via rotational invariance techniques (ESPRIT) [2], or method of direction estimation (MODE) [3] have been applied. However, in a complicated multipath environment such as urban areas, it seems difficult to find the positions of radio stations accurately by using the DOA estimation with these approaches. Therefore, it is necessary to introduce the concept of microcells for accurately finding illegal radio stations in the urban area.

In this research, a novel method for estimation of the source location of the electromagnetic wave in the urban area is proposed. This method includes two processes which are the measurement of "Forward Receiving Pattern (FRP)" and the calculation of "Backward Receiving Pattern (BRP)". The source location can be estimated from the information of the FRP and BRP. Results are shown to demonstrate the effectiveness of the proposed method.

2. ESTIMATION METHOD

The proposed method is based on reciprocity relation of transmitting and receiving antennas. It is assumed that the radiation pattern of the source which is the target to be searched for is omni directional in the horizontal plane, and sizes of transmitting and receiving antennas are sufficiently small compared with the propagation area. Additionally, the geometry and location of all involved buildings are known. The proposed method is composed of the following three steps.

A. *FRP Measurement*

In the first step, the EM wave radiated from the source is measured at different azimuth angles at an observation point. The function of the received power versus the azimuth angle is referred as "Forward Receiving Pattern (FRP)". In order to estimate DOA, lots of methods have been used such as rotating antenna having high directivity in the azimuth plane, the beamformer method and Capon's method [4] using an array antenna. In this paper, the MUSIC algorithm is applied to the measured data to improve the resolution with the azimuth angle.

B. *BRP Calculation*

In the second step, the received power at the estimation points in the area, where the EM source may exist, is evaluated by the numerical analysis, when the transmitter with high directivity is assumed to be located at the same position of the observation point in step 1. Patterns of the received power versus the azimuth angle of the main lobe of the transmitter are calculated, and these patterns are referred as the "Backward Receiving Pattern (BRP)". The BRP at each estimation point is equivalent to the receiving pattern at the observation point in the case that the wave source would be located at the estimation point, because of the reciprocity relation of transmitting and receiving antennas. Since the location of the wave source is determined among the BRP positions at the next step, the BRP should be evaluated at many estimation points to form a database in advance. In this database, lots of the BRP in the area where the wave source may exist are recorded.

Although the Method of Moments (MoM) [5] and Finite Difference Time Domain (FDTD) method [6] are effective methods in evaluating the EM field distribution in the multipath environment, these techniques require too much computer memory and CPU time in the case of electrically large analysis area such as the urban areas at microwave band. Ray tracing method is based on a high frequency approximation and is widely used for many problems including the propagation in mobile communications [7]-[10]. Since the sizes of buildings and distance between the source and observation point are much larger than the wavelength, BRP are evaluated by the technique based on the ray tracing method.

C. **Comparison between BRP and FRP**

In the third step, the values of the BRP within the area, where the wave source is probably located, are compared with the FRP. The position having the strongest correlation between the BRP and FRP is considered to be the possible location of the wave source. The correlation coefficient between BRP and FRP is given by

$$f_{EV}(\vec{r}) = \int \frac{\left(P_B(\phi,\vec{r}) - \overline{P}_B(\vec{r})\right)\left(P_F(\phi,\vec{r}_o) - \overline{P}_F(\vec{r}_o)\right)}{\sigma_{P_B}(\vec{r})\sigma_{P_F}(\vec{r}_o)} d\phi$$

where $\vec{r}$ and $\vec{r}_o$ denote positions of the estimation point and the observation point, P_B and P_F denote the BRP and FRP, respectively. $\overline{P}$ and σ_P are the average and the standard deviation of P with respect to the azimuth angle ϕ.

By using the method described above, the possible locations of the electromagnetic source can be found. However, in practical cases, it is usually difficult to determine where the real location of the wave source is because several locations with high correlation coefficient may be found. This problem can be solved by repeating the above three steps at several observation points.

3. FRP MEASUREMENT

An experiment was carried out at frequency of 2.45GHz. The estimation environment is shown in Fig.1, which is the roof of the main building of Electrical Engineering in Tohoku University. There is a large room with concrete structure on the center of the roof which is more than about 20 meters long, 5 meters wide and 3 meters high. And 10 exterior units of airconditioners, which are higher than 2 meters, are located on the right side of the roof. The positions of the EM wave source and 2 observation points are also shown in Fig.1. 2.45GHz CW wave is radiated from the EM wave source.

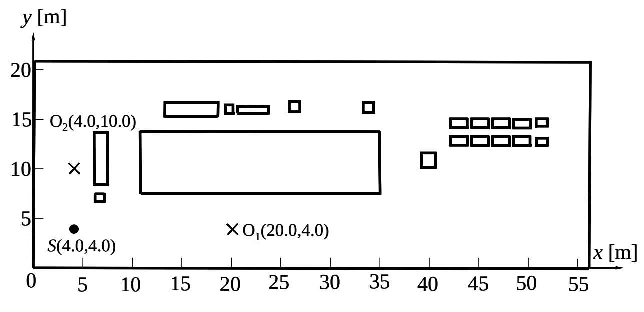

Fig.1. Estimation Environment of LOS.

The value of FRP at step A is measured from received signals of array elements. Fig.2 shows the 6 × 6 receiving sleeve array antenna. The spacing between elements is 0.4167λ. Since it is difficult to distinguish the multiple waves which are strongly correlative by only the conventional MUSIC algorithm, the spatial smoothing pre-processing (SSP) technique [11],[12] with 3 × 3 subarrays is applied as the pre-processing of MUSIC algorithm. A sleeve dipole antenna is employed as the receiving antenna and is scanned to form a equivalent 6 × 6 planar array antenna. The transmitting sleeve dipole antenna is fixed at height of 1.51 meter above the floor, and the receiving array antenna is also located 1.51 meter in height, so that the transmitting and the receiving antennas are in a same horizontal plane.

In order to obtain FRP in step A, MUSIC spectrum is evaluated. DOA is then estimated from peaks of MUSIC spectrum. FRP is formed by using the values of DOA and received powers at these DOA, and taking the convolution between these values and a sinusoidal beam having 3dB beamwidth of 9°.

Fig.3 shows an example of FRP obtained at observation point O_1.

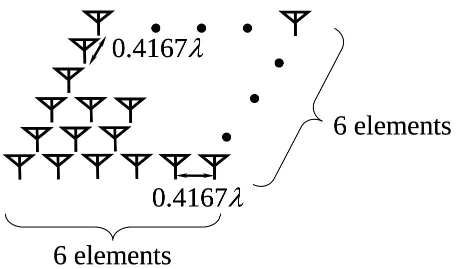

Fig.2. Receiving planar array.

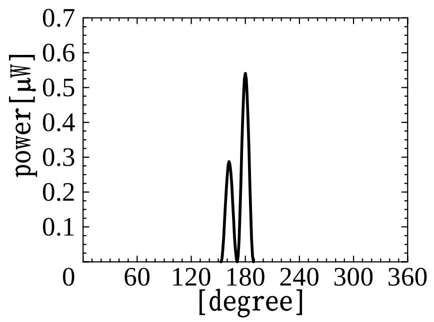

Fig.3. FRP obtained at observation point O_1.

4. BRP CALCULATION

The image method is applied as the ray tracing method. The scattering buildings are assumed to be perfect conductors.

The transmitter, which is located at the same position of the observation point at step A, launches beams at interval of every 5 degrees. And the half-power angle is 3 degrees.

The number of the scattered waves is limited by the following rules to save the CPU time. The reflection by the vertical walls is limited to be less than 2 times based on the assumption that there are no scatterers outside of the analysis area and only a few reflected rays contribute in the limited area. The diffraction at the vertical edges is not considered.

The BRP at the centers of 27 × 20 cells in the area of 54m × 20m are calculated.

Fig.4 shows BRP obtained at the cell where EM source exists when observation point is O_1.

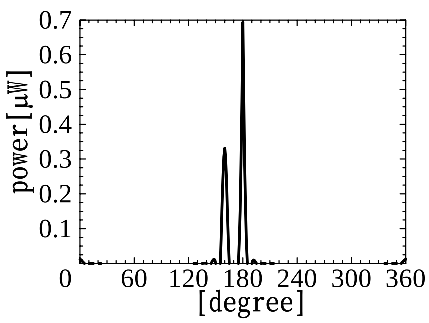

Fig.4. BRP obtained at the cell where EM source exists when observation point is O_1.

5. RESULTS

I *LOS environment*

The correlation coefficient between FRP and BRP is evaluated at each cell. Results of the correlation coefficient is shown in Fig.3, where Fig.5-(a) and Fig.5-(b) are the results by the FRP obtained at observation points O_1 and O_2, and Fig.5-(c) is superimposed the case of observation points O_1 and O_2. The white color corresponds to low correlation ($f_{EV} = 0$) while the black means high correlation ($f_{EV} = 1$) which means the high possibility of the existence of the source to be searched for. In Fig.5-(c), it is clear that the possible points are found around the actual position of the source.

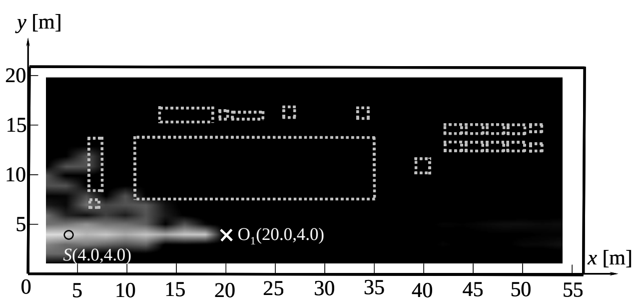

Fig. 5-(a) Result from observation point O_1

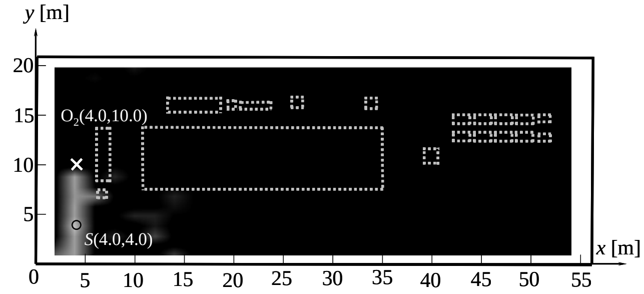

Fig. 5-(b) Result from observation point O_2

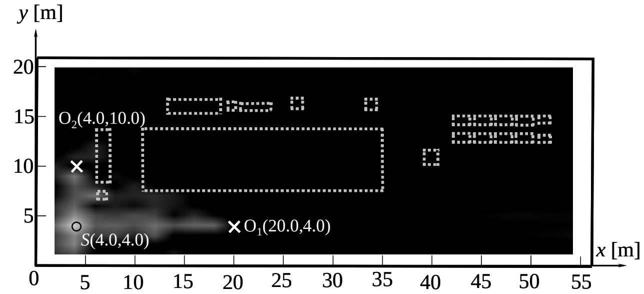

Fig. 5-(c) Result from observation point O_1 and O_2

Fig.5. Correlation coefficient between FRP obtained by measured receiving signals at O_1, O_2 and BRP on each cell.

II *N-LOS environment*

A conducting planar scatterer is placed at (*x*, *y*)=(4.0,6.83) as shown in Fig. 6 in order to make Non-Line-Of-Site(NLOS) environment. Results of the correlation coefficient are shown in Fig.7, where Fig.7-(a) is the results by the FRP obtained at observation point O_2', and Fig.7-(b) is superimposed the case of observation points O_1' and O_2'. The results by the FRP obtained at observation point O_1' is the same to Fig.3-(a)

It is clear that the accuracy and the resolution of the estimation of the source location are improved by superimposing the estimation results in the cases of several observation points.

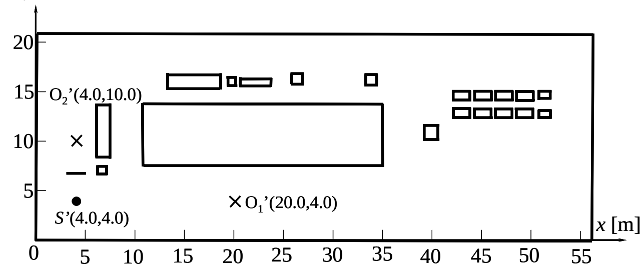

Fig.6. Estimation Environment of N-LOS.

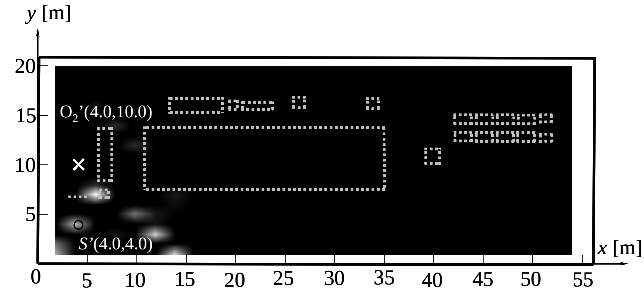

Fig. 7-(a) Result from observation point O_2'

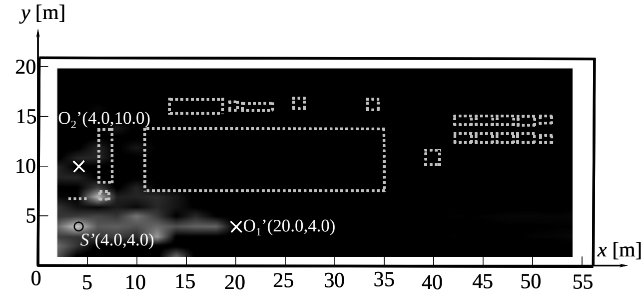

Fig. 7-(b) Result from observation point O_1' and O_2'

Fig.7. Correlation coefficient between FRP obtained by measured receiving signals at O_1', O_2' and BRP on each cell.

6. CONCLUSIONS

A novel method to estimate the source location of EM waves in complicated multipath urban areas has been developed. The results show that the area with the high correlation coefficients between the FRP and the BRP indicates the location of actual source demonstrating the validity of the proposed method. The proposed method can be applied to searching for the illegal radio station in urban areas accurately in the multi-path environment.

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