Identification of Line of Sight by Cross Polarization Characteristic

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Abstract— **In this paper, we identified line of sight (LOS) by cross polarization discrimination (XPD). We analyzed the propagation characteristic by the Finite Difference Time Domain (FDTD) method, and statistically evaluated the performance of the LOS identification based on XPD. As a result of the evaluation, we found it is difficult to obtain sufficient identification performance only by XPD. Therefore, we developed a new identification method combining XPD and the received power. By using the method, we showed successful identification rate of about 80% could be obtained.**

***Keywords*—LOS, XPD, FDTD, Indoor propagation**

I. INTRODUCTION

Identification of line of sight (LOS) between a transmitter and a receiver is important for various wireless applications [1]. For example, range measurement based on radio arrival time is highly precise in LOS, but the precision is expected to deteriorate in a non line of sight (NLOS) situation where the transmitted signal could reach the receiver through reflected and/or diffracted path and the total path length is different from that of the direct path [2, 3]. If LOS can be identified at the receiving side, improvement of the accuracy of the range measurement is possible. By applying this to a terminal location estimation system where the location is estimated based on the distances to base stations, we can improve the estimation accuracy. In addition, wide variety of applications of the LOS identification are expected.

Various NLOS identification methods have been proposed in the past [1, 3-7]. In this paper, we focus on Cross Polarization Discrimination (XPD) as a way to identify LOS. This paper clarifies the LOS identification characteristic by XPD based on radio wave propagation analysis by FDTD.

II. CROSS POLARIZATION DISCRIMINATION (XPD)

XPD shows mutual leakage of the principal and the cross polarized waves, and is defined as follows.

$$\mathrm{XPD} = \frac{[\text{principal polarization electric power}]}{[\text{cross polarization electric power}]} \tag{1}$$

Polarization of a direct wave does not change as travelling of radio wave, so the cross polarization electric power is zero and XPD becomes infinity. On the other hand, at reflection or diffraction, when the radio wave incidents to the reflection surface or the diffraction edge obliquely, the direction of the polarization changes and the cross polarization component appears. It results in the decrease of XPD. Therefore it is conceivable that XPD has close relation to LOS and it seems possible to identify LOS according to XPD.

III. LOS IDENTIFICATION METHOD

As mentioned above, XPD and LOS are thought closely related. In this paper we consider a LOS identification method based on XPD. For a comparison, we identify LOS by the received power. The detail procedure of those identification methods are shown below.

A. XPD-based identification

Let γ be XPD at a receiving point. In this method, we identify LOS/NLOS according to the following decision criteria:

$$\begin{cases} \gamma \geq \gamma_{\mathrm{th}}, & \mathrm{LOS} \\ \gamma < \gamma_{\mathrm{th}}, & \mathrm{NLOS} \end{cases} \tag{2}$$

where γ_{th} is the threshold value of XPD by which LOS/NLOS is identified. The value greatly affects the identification performance so it should be carefully selected. In this paper we use a value where the difference between the cumulative probability of LOS and NLOS becomes the maximum as shown later. It means we assume an optimal case. We assume such an ideal case to consider the upper limit of the identification performance of the method.

B. Received power-based identification

In an NLOS environment, since the direct wave does not reach, the received power is considered to be low. Hence the received power has relation to LOS. Based on this observation, we attempt an identification method using the received power. In this method, we identify LOS/NLOS according to the following judgement. We set the optimal threshold P_{th} by the same way as XPD-based identification.

$$\begin{cases} P \geq P_{\mathrm{th}}, & \mathrm{LOS} \\ P < P_{\mathrm{th}}, & \mathrm{NLOS} \end{cases} \tag{3}$$

C. Hybrid method using XPD and received power

As shown quantitatively later, we show the identification performances of the two methods presented above where

XPD and the received power are used separately. In addition, in order to realize the higher identification rate, we propose a new identification method combining XPD and the received power.

As shown later, by the XPD-based identification, the successful identification rate except in the area near the transmitting point was high. Moreover by the received power-based identification, we could identify LOS in the area near the transmitting point. Therefore, it is natural to take the both advantage and appropriately combine them to realize the better identification performance.

In this method, we identify LOS by the received power first. We set a new threshold value for the received power P'_{th} in order to identify the LOS in the vicinity of the transmitting point successfully. Receiving points having the larger power than this threshold are judged as LOS. At the other receiving points where the received power is less than the threshold, we use the XPD-based identification as above mentioned. We use the same threshold γ_{th} also for this case.

$$\begin{cases} P \geq P'_{\mathrm{th}}, & \text{LOS} \\ P < P'_{\mathrm{th}}, & \begin{cases} \gamma \geq \gamma_{\mathrm{th}}, & \text{LOS} \\ \gamma < \gamma_{\mathrm{th}}, & \text{NLOS} \end{cases} \end{cases} \tag{4}$$

IV. INDOOR PROPAGATION ANALYSIS BY FDTD

We compose ten test environments of a room model (size: 10 m × 8 m × height 3 m) where five objects like furniture (size: 1 m × 1 m × height 2 m, material: metal) are placed at random positions in the room. We set the transmitting point at (9.0, 7.0, 2.8) in those environments. In FDTD calculation, we set mesh of 0.025m in whole analysis area, and regard these mesh points as receiving points. Then we calculate the electric powers of the principal polarization and the cross polarization components at receiving points by the FDTD method. We excited signal by providing electric field in the z-axis direction at a cell of transmitting point. This corresponds to emission by microdipole in the vertical polarization. The parameters used for FDTD are presented in TABLE I. We estimate the statistical relation of LOS with the obtained XPD and find the LOS identification characteristics by XPD.

Fig. 1 shows an example of ten indoor test environments. The squares indicate blocking objects. The black part of the figure is the NLOS situation from the transmitting point at 1.0 m height. We use a commercial FDTD simulator called EEM-FDM for the calculation [8]. It took 195.7 seconds for the calculation in this environment (number of cells: 480 × 400 × 200) by a PC with Intel(R) Core(TM) i7-5930K 3.50 GHz CPU and 64.0 GB memory.

Figs. 2 and 3 show the spatial distribution of the vertical and horizontal polarization components of the received power. The received power is given as the relative power to the transmitted power. Fig. 4 shows the spatial distribution of XPD in the environment. As shown in Figs. 2 and 3, the

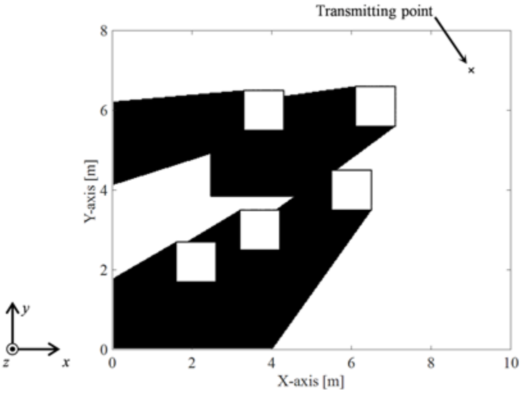


Fig. 1. An example of test environments.

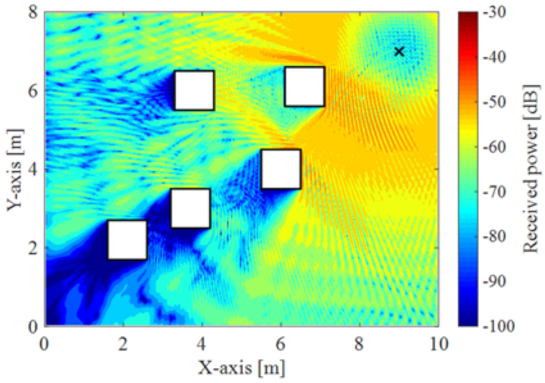


Fig. 2. Spatial distribution of received power for vertical polarization.

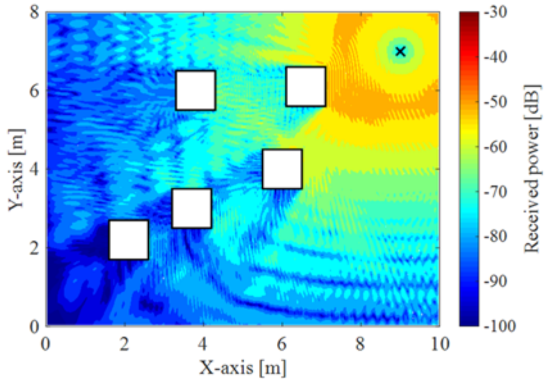


Fig. 3. Spatial distribution of received power for horizontal polarization.

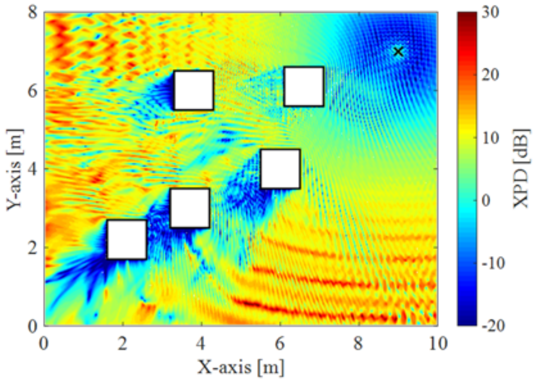


Fig. 4. Spatial distribution of XPD.

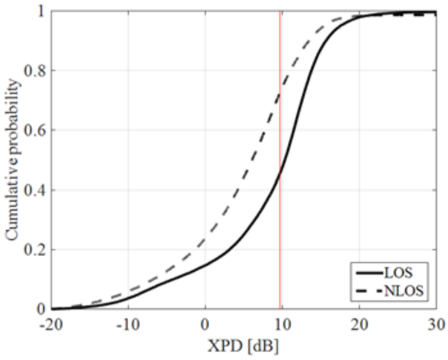


Fig. 5. CDF of XPD.

TABLE I. SIMULATION PARAMETERS

Frequency	1.0 GHz
Transmitting polarization	Vertical
Height of receiving point	1.0 m
Material of wall	Concrete
FDTD cell size	0.025 m × 0.025 m × 0.025 m

horizontal polarization power is larger than the vertical polarization power in NLOS environment of the lower left of the figure. Further from Fig. 4, we can confirm that XPD in the back side of the objects is generally low. Fig. 5 shows cumulative distribution function (CDF) of each XPD in LOS and NLOS for Fig. 4. This figure shows the rate of receiving points of which XPD is less than the horizontal value. The red line in Fig. 5 shows the XPD value where the difference between the cumulative probability of LOS and NLOS becomes the maximum, and the value is 9.70 dB. We use the value as the threshold for LOS/NLOS identification described later. As can be seen from Fig. 5, XPD in the LOS environment is larger than in the NLOS environment. Also the other nine environments had similar results. From this result, it is expected that we can identify LOS by XPD.

V. EVALUATION RESULT OF LOS IDENTIFICATION

Fig. 6 shows the result of the LOS identification by the XPD-based method in the environment of Fig. 1. The red area in the figure shows misidentification where it is identified as LOS in the NLOS environment. The blue area shows the opposite miss cases. The green area shows successfully identified locations. The percentage of the successful identifications in this environment was 61.30%.

The spatial distribution of the received power, CDF of the received power, and the LOS/NLOS identification result by the received power-based method are shown in Figs. 7, 8, and 9, respectively. They are for the same test environment shown in Fig. 1. The value of P_{th} is -65.61 dB. As shown in Fig. 8, the received power in the LOS is larger than in the NLOS.

The percentage of the successful identifications by the received power-based method was 79.33%, and this is better than the XPD-based method. Comparing Fig. 6 and Fig. 9, by the XPD-based identification, we can see many misidentification cases in LOS near the transmitting point.

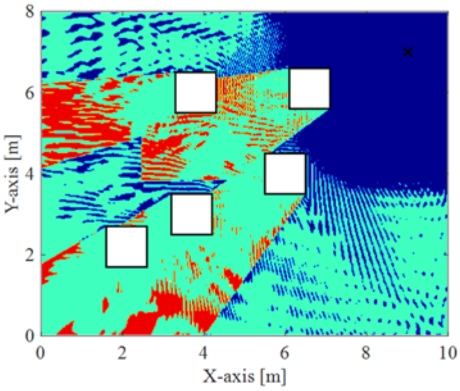


Fig. 6. LOS identification result of XPD-based identification.

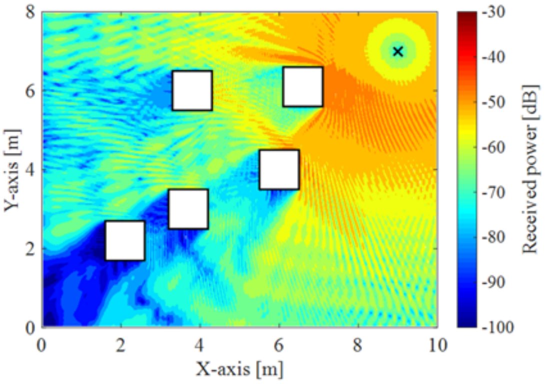


Fig. 7. Spatial distribution of received power.

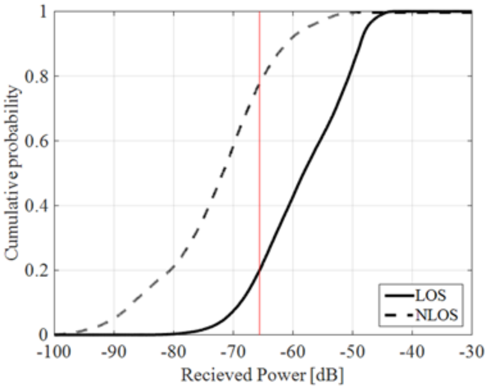


Fig. 8. CDF of received power.

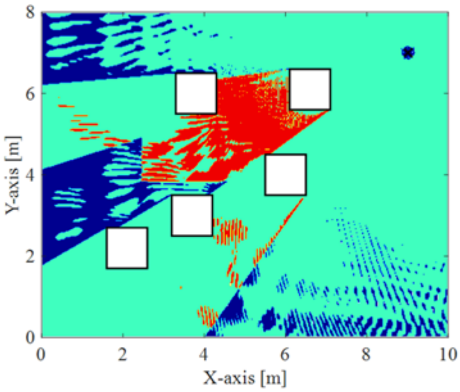
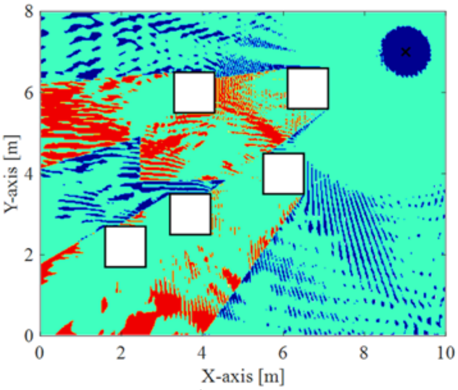
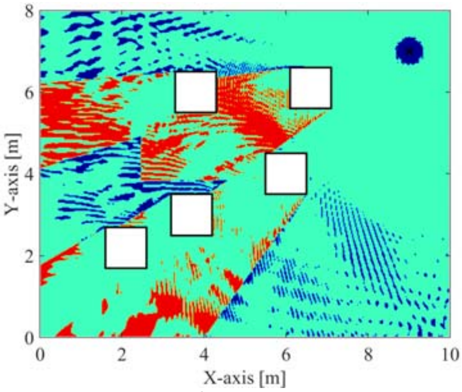


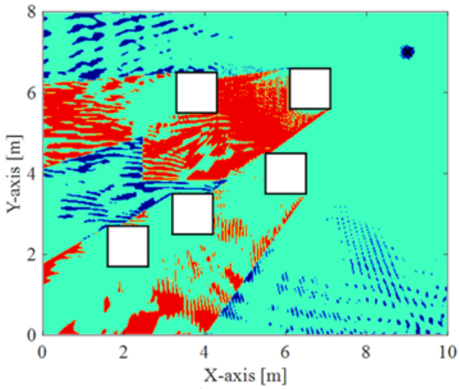
Fig. 9. LOS identification result of received power-based identification.



(a) $P'_{\mathrm{th}} = -55$ dB



(b) $P'_{\mathrm{th}} = -60$ dB



(c) $P'_{\mathrm{th}} = -65$ dB

Fig. 10. LOS identification result of hybrid method using XPD and received power.

TABLE II. SUCCESSFUL IDENTIFICATION RATES BY HYBRID METHOD USING XPD AND RECEIVED POWER

P'_{th}	Overall	LOS area	NLOS area
-55 dB	80.99 %	85.46 %	72.98 %
-60 dB	82.41 %	89.65 %	69.46 %
-65 dB	81.36 %	92.78 %	60.93 %

This is due to the directivity of the microdipole: radio waves do not radiate to the upward and downward directions of the antenna and XPD reduces. Further by the received power-based identification, we see that many misidentification cases are found in LOS in the distant area from the transmitting point. Also many misidentifications are found in NLOS near the transmitting point (The central red area of Fig. 9). This is because the power is large in the area near the transmitting point even in NLOS, and the power is low in the distant area from the transmitting point even in LOS. From these facts, it is thought that LOS/NLOS identification is improved by combining XPD and the received power. Based on this idea, we devised a new method described in III-*C*. In this method, we identify LOS by using the received power at first, then identify LOS/NLOS by using XPD. The result by the identification method is shown in Fig. 10 and the successful identification rates are summarized in TABLE II. The threshold value P'_{th} was set to -55, -60 and -65 dB. With the smaller P'_{th}, we can see that the identification performance in LOS around the transmitting point is improved, but the identification performance in NLOS around the transmitting point (in the upper middle area of Fig.10) decreases slightly. Among the three threshold values, the overall successful identification rate with $P'_{\mathrm{th}} = -60$ dB is the best and it was 82.41%. It shows the success rate of identification is improved compared to the XPD-based and the received power-based methods.

VI. CONCLUSION

In this paper, we analyzed XPD in indoor environments by FDTD. Then we try to identify LOS/NLOS by using XPD. However, the percentage of the correct identifications remained about 60%. For comparison, we attempted an identification method using the received power. In order to obtain high success rate of identification than these methods, we developed a new hybrid method where XPD and the received power are used. The identification performance was improved in comparison to the methods using only XPD or the received power, and as a result, the percentage of the correct identifications increases to about 80%.

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