Fundamental Study on Channel Model of MIMO sensor for Event Detection

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Abstract

In recent years, researches on radio security sensors by using multi-antenna or MIMO system have been attracting attention. Many systems or algorithms have proposed. To evaluate various algorithms, statistical channel model for the system should be established. In this report, we analyze the channel model of the MIMO security sensor.

Keywords : MIMO Security sensor Rayleigh distribution Rice distribution Channel matrix

1. Introduction

Security sensors by using radio wave have been attracting attention recently. These methods differ from the classical radio sensors in the detection criteria. Though the classical sensor detects the events by using receiving power change, the emerging methods utilize radio-wave propagation change to detect them. Therefore robust detection can be realized. One of the event detection methods with an array antenna uses signal eigenvector with a SIMO (Single-Input Multiple-Output) system to detect events [1]. In addition, the methods using MIMO (Multiple-Input Multiple-Output) has been proposed [2]. This method detects an event by using the change of MIMO channel matrix.

Many detection algorithms with various systems have proposed. However, those methods are evaluated only in a particular environment numerically or experimentally. Quantitative evaluation including comparison will be required for further study. The propagation channel model for such a system is necessary for the purpose. In this paper, we evaluate the channel model of the MIMO sensor by the ray tracing method.

2. Data Model

We consider a MIMO system consisting of M transmitting and N receiving antennas. Assuming that the received vector by the m-transmitting antenna on the time without an event (t = 0) can be written by

$$\boldsymbol{y}_m(0) = \boldsymbol{h}_m(0)x_m(0) + \boldsymbol{n}_m(0), \quad m = 1,2,\cdots,M, \tag{1}$$

where $\boldsymbol{y}_m$ is the N dimensional column vector, $x_m(0)$ is the transmitting signal, $\boldsymbol{h}_m(0)$ is the propagation channel vector for the m-th transmitting channel and $\boldsymbol{n}_m(0)$ is the N dimensional additive white Gaussian noise vector. Similarly, the received vector at time t can be written by

$$\boldsymbol{y}_m(t) = \boldsymbol{h}_m(t)x_m(t) + \boldsymbol{n}_m(t), \quad m = 1,2,\cdots M. \tag{2}$$

The channel matrices at time t = 0 and time t can be written by

$$\boldsymbol{H}(0) = [\boldsymbol{h}_1(0), \boldsymbol{h}_2(0), \cdots \boldsymbol{h}_M(0)], \tag{3}$$
$$\boldsymbol{H}(t) = [\boldsymbol{h}_1(t), \boldsymbol{h}_2(t), \cdots, \boldsymbol{h}_M(t)]. \tag{4}$$

Obviously, change of the channel matrix by the event, $\boldsymbol{H}_d$(t), can be derived by

$$\boldsymbol{H}_d(t) = \boldsymbol{H}(t) - \boldsymbol{H}(0), \tag{5}$$

$$\boldsymbol{H}_d(t) = [\boldsymbol{h}_{d,1}(t), \boldsymbol{h}_{d,2}(t), \cdots, \boldsymbol{h}_{d,M}(t)], \tag{6}$$

where $\boldsymbol{h}_d$(t) is the change of the channel matrix by the event for the *m*-th transmitting channel. In the followings, we evaluate statistical channel models and their distribution by the ray tracing method.

3. Signal Model

It is necessary for quantitive analysis of various event detection algorithm to develop typical statistical channel model. In the MIMO sensor, it is difficult to discuss what is “typical” channel model because the antennas are widely distributed and the propagation change may highly depends on the propagation environment, *i.e.* room size, as well as antenna arrangement. Therefore, in this section, we analysis channel matrices and its change, $\boldsymbol{H}$(0) and $\boldsymbol{H}_d$(t), for the room shown in Fig.1, as an example by the ray tracing method. Detailed simulation parameters of the room/intrusion and the adopted MIMO system are listed in Table 1 and 2, respectively. Here, we evaluate the channel obtained by the 4×4 MIMO system without 4 locations of intruder, respectively, shown in Fig. 1.

Table 1: Propagation environment parameters

Room depth & width& height [m]	6.8 × 7.8 × 2.7
Number of maximum reflection	3
Permittivity of wall	6.25
Conductivity of wall [S/m]	0.0814
Intruder depth & width & height [m]	0.5 × 0.2 × 1.8
Permittivity of intruder	42.1
Conductivity of intruder [S/m]	0.514

Table 2: Simulation parameters

Number of transmitting antenna	4
Receiving array form	ULA
Number of receiving antenna	4
Element separation of receiving array [cm]	6.25

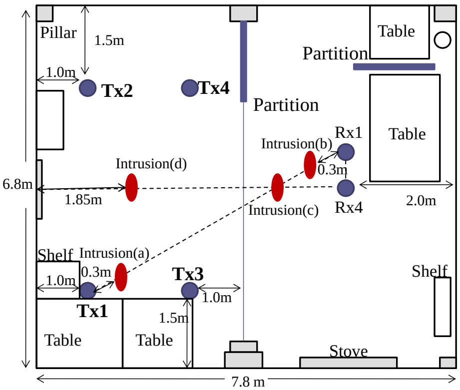

Figure 1: Propagation environment model

3.1 **Channel Model for *H*(0)**

In the radio security sensor, antenna arrangement to realize multipath-rich environment will be preferable. Therefore, elements of $\boldsymbol{H}$(0) will have the Nakagami-Rice distribution with low K factor is 1~3 in LOS (Line-of-Sight) case or the Rayleigh distribution in NLOS (Non-Line-of-Sight) case. Figure 2 shows the CDF (Cumulative Distribution Function) of the amplitude of $\boldsymbol{H}$(0) obtained by the simulations. CDF of the amplitude of $\boldsymbol{H}$(t) for the intrusion (c) is also shown in this figure. The Rayleigh and Nakagami-Rice distribution (K = 3) are also plotted for references. Each distribution is normalized to correspond with 50% of CDF of $\boldsymbol{H}$(0). As shown in this figure, the elements of $\boldsymbol{H}$(0) is close to the Nakagami-Rice distribution (K = 3) and those of $\boldsymbol{H}$(t) is almost Rayleigh distribution. As expected, these results show that the initial distribution for $\boldsymbol{H}$(0) and $\boldsymbol{H}$(t) is the Rayleigh and Nakagami-Rice depending its Line-of-Sigh condition. Figure 3 shows the amplitude of $\boldsymbol{H}$(0). As shown in Fig.3, the amplitude of $\boldsymbol{H}$(0) distributes uniformly.

3.2 **Channel Model for $\boldsymbol{H}_d$(t)**

Next, we consider distribution of channel change, $\boldsymbol{H}_d$(t). Amplitude of each element in $\boldsymbol{H}_d$(t) will have a characteristic distribution depending on the location of the event. Mathematically, 4 types of the typical distribution will be given for $\boldsymbol{H}_d$(t). The first is the model which is uniform

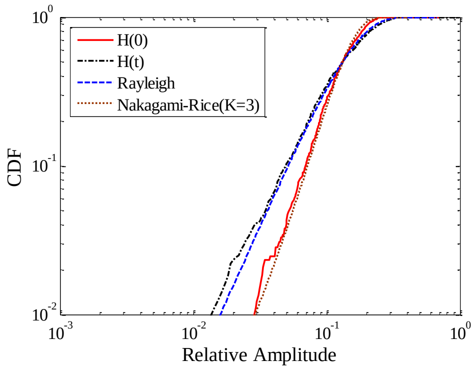

Figure 2: CDF of $\boldsymbol{H}(0)$ and $\boldsymbol{H}(t)$

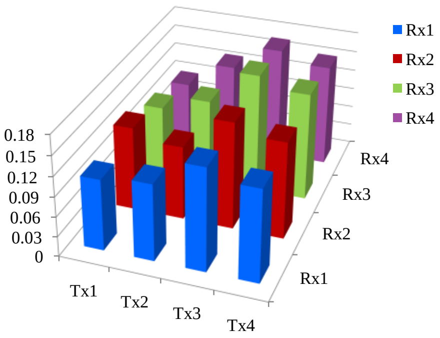

Figure 3: Amplitude of $\boldsymbol{H}(0)$

variation. This is the model that a variation is uniformly distributed all over the channels. The second is the column variation model, that may obtain for the case when the specific channel of a transmitter is blocked by the intrusion. The third is the row variation model that will occur when the separation of receiving antenna is large enough and the event occurred close to a certain receiving antenna. The last is the delta model that shows variation in the (i, j) element only. In the followings, we analyze what type of distribution $\boldsymbol{H}_d(t)$ is obtained in the simulation model shown in Fig. 1.

Figure 4 shows the CDF of the elements in $\boldsymbol{h}_{d,1}(t)$ when event occurred at (a). In the figure, we also show the CDF of $\boldsymbol{h}_{d,2}(t)$. In this subsection, each distribution is normalize to correspond with 50% of CDF of $\boldsymbol{h}_{d,1}(t)$. In addition, Figure 5 shows the amplitude of elements in $\boldsymbol{H}_d(t)$. As shown in Fig. 5, $\boldsymbol{H}_d(t)$ for the event at (a) is close to the column variation model. As shown in Figure 4, statistical variation of $\boldsymbol{h}_{d,1}(t)$ has the Nakagami-Rice distribution. Clearly this was happen because of the LOS signal is blocked by the intrusion. The elements in other $\boldsymbol{H}_d(t)$ channels are very small having Rayleigh distribution.

Figure 6 show the CDFs of the elements in $\boldsymbol{h}_{d,1}(t)$ and $\boldsymbol{h}_{d,2}(t)$ when event occurred at (b), respectively. Figure 7 show the amplitude distribution of $\boldsymbol{H}_d(t)$ in this 4×4 measurement. As shown in Fig. 7, the $\boldsymbol{H}_d(t)$ is close to the uniform variation model. This is because the event interrupted all direct waves of the transmitters. As shown in Fig. 7, when $\boldsymbol{H}_d(t)$ vary in this way, statistical distribution of the elements in $\boldsymbol{H}_d(t)$ becomes almost the Nakagami-Rice distribution.

The final example is the $\boldsymbol{H}_d(t)$ at intrusion (d). The CDF of $\boldsymbol{h}_{d,1}(t)$ and $\boldsymbol{h}_{d,2}(t)$ are shown in Fig. 8. In addition, Figure 9 show the amplitude distribution of the $\boldsymbol{H}_d(t)$. As shown in Fig. 9, $\boldsymbol{H}_d(t)$ is close to the uniform variation model. The amplitude of them is small because the intrusion (d) only interrupts multipath waves. Each element of $\boldsymbol{H}_d(t)$ in this case has the Rayleigh distribution.

From these results, we can understand that the channel model for $\boldsymbol{H}_d(t)$ can be derived by the Rayleigh or Nakagami-Rice distribution depending on the channel change by the intrusion. Note that the amplitude distribution of the channel matrix has different characteristic in comparison with the conventional MIMO channel for indoor communication. This is because the transmitting and receiving antennas are widely separated in the MIMO security sensor.

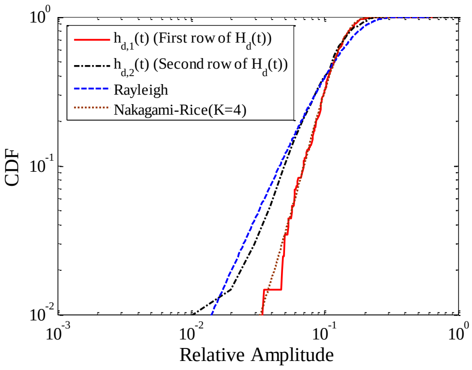

Figure 4: CDF of $\boldsymbol{H}_d(t)$ (event occurred at (a))

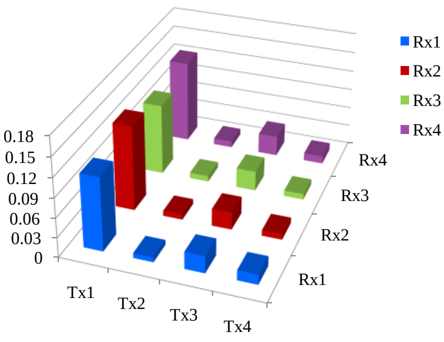

Figure 5: Amplitude of $\boldsymbol{H}_d(t)$ (event occurred at (a))

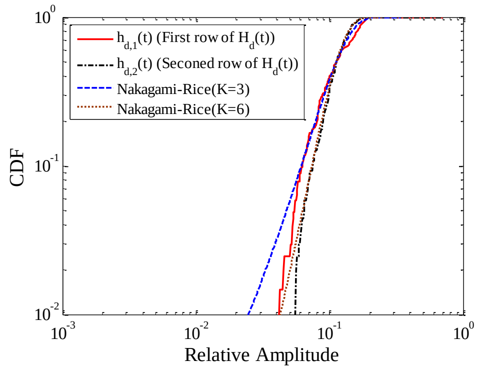

Figure 6: CDF of $\boldsymbol{H}_d$(t) (event occurred at (b))

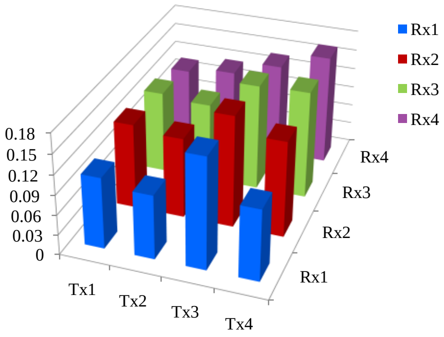

Figure 7:Amplitude of $\boldsymbol{H}_d$(t) (event occurred at (b))

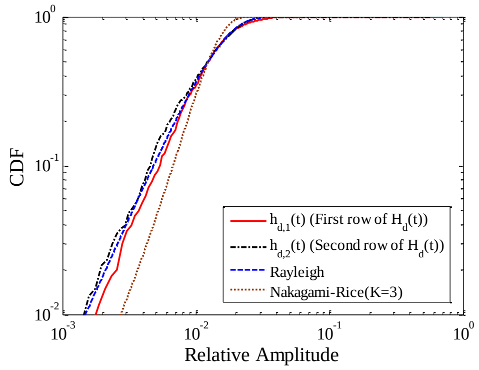

Figure 8:CDF of $\boldsymbol{H}_d$(t) (event occurred at (d))

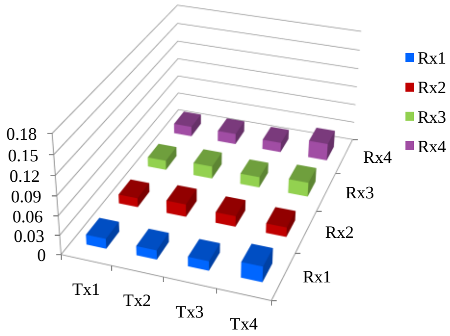

Figure 9:Amplitude of $\boldsymbol{H}_d$(t) (event occurred at (d))

5. Conclusion

In this paper, we have evaluated the statistical signal model of the channel matrix change for the MIMO sensor. We demonstrated that the distribution of amplitude of the channel when an event doesn't occur is close to the Rayleigh distribution or Rice distribution with low K-factor. The change of the channel matrix by an event can be modelled by the Nakagami-Rice or Rayleigh distribution depending on direct waves are interrupted or not by the event. In addition, we have shown the amplitude distribution of $\boldsymbol{H}_d$(t) for several typical locations of the event occurred.

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