MIMO Sensor
– Effectiveness of distributed MIMO antenna configuration –

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1 Introduction

Reliable security systems have been recently attracted much attention. To realize this, the microwave sensor using existing signals, such as wireless LAN, TV broadcast signals and so on, have been studied. Moreover, intruder detection using array signal processing is proposed [1]. In this method, Single Input Multiple Output (SIMO) channel is assumed and the variation on the eigenvector, which is obtained by the correlation matrix of the received signal, is utilized as a cost function of the event detection. However, since the value of cost function in this method is very high, the detection accuracy greatly depends on signal to noise ratio (SNR).

This paper proposes the intruder detection method which utilizes the eigenvectors for both transmitter and receiver site, when using Multiple Input Multiple Output channel. We call this method as *MIMO Sensor*. Although the channel capacity on the MIMO transmission is severely degraded in time variant channels [2], we use this feature as an underhanded way in the *MIMO Sensor*. We propose the use of time correlation function for the transmitting and receiving eigenvectors in the MIMO channel. Moreover, we evaluate the effectiveness of proposed method by using an actual indoor environment. In particular, we clarify the effectiveness of distributed antenna configuration using the measured data.

2 Proposed method

In this paper, we utilize the variation of eigenvectors for both transmitter and receiver sites in MIMO channel. When M and N are the number of transmitting and receiving antenna, the channel matrix $\boldsymbol{H} \in \mathbb{C}^{N\times M}$ can be transformed by using a singular value decomposition as,

$$\boldsymbol{H} = \boldsymbol{U}\boldsymbol{D}\boldsymbol{V}^H, \tag{1}$$

where $\boldsymbol{V} \in \mathbb{C}^{M\times M}$ and $\boldsymbol{U} \in \mathbb{C}^{N\times N}$ denote eigenvector at the transmitter and receiver site. $\boldsymbol{D} \in \mathbb{C}^{N\times M}$ is the diagonal matrix and the diagonal elements of $\boldsymbol{D}$ are the square root of the eigenvalues of $\boldsymbol{H}\boldsymbol{V}\boldsymbol{V}^H\boldsymbol{H}^H$. We realize the intrusion detection by checking the variation of eigenvectors, $\boldsymbol{V}$ and $\boldsymbol{U}$. The variation of the eigenvector can be expressed by time correlation function. Let us assume that $v_{no,ij}$ $(i = 1 \sim N, j = 1 \sim M)$ is a component at the transmitting eigenvector without people in the room. When $v_{ij}(t)$ is a component of the transmitting eigenvector on time t, the time correlation at the eigenvector on the transmitter is represented by

$$\rho_T(t) = \frac{\left|\sum_{i=1}^{N}\sum_{j=1}^{M} v_{no,ij}^{*} v_{ij}(t)\right|}{\sqrt{\sum_{i=1}^{N}\sum_{j=1}^{M}|v_{no,ij}|^2}\sqrt{\sum_{i=1}^{N}\sum_{j=1}^{M}|v_{ij}(t)|^2}}. \tag{2}$$

Next, let us assume that $u_{no,ij}$ $(i = 1 \sim N, j = 1 \sim M)$ is a component at the receiving eigenvector without people in the room. When $u_{ij}(t)$ is a component of the receiving eigenvector on time t, the time correlation at the eigenvector on the receiver is shown as follows:

$$\rho_R(t) = \frac{\left|\sum_{i=1}^{N}\sum_{j=1}^{M} u_{no,ij}^{*} u_{ij}(t)\right|}{\sqrt{\sum_{i=1}^{N}\sum_{j=1}^{M} |u_{no,ij}|^2}\sqrt{\sum_{i=1}^{N}\sum_{j=1}^{M} |u_{ij}(t)|^2}} \tag{3}$$

Here, we assume that $v_{no,ij}$ and $u_{no,ij}$ can be measured in advance as the knowledge for the intrusion detection. In this paper, the following equation is used as the function for the intrusion detection, because both transmission and reception diversity effects are expected.

$$\rho(t) = \rho_T(t) \cdot \rho_R(t) \tag{4}$$

3 Measurement environment

To clarify our proposed intrusion detection, we conducted the measurement in an actual indoor environment. The measurement environment is shown in Fig. 1. The size of room is 7.8 × 6.8 × 2.6 m. During the measurement, the transmitter and receiver are fixed in Line-of-sight (LOS) position. The number of transmit and receive antennas are two, respectively: 2×2 MIMO channel measurement is employed. Radio frequency and bandwidth are 2.4 GHz and 10 MHz, respectively. The transmit power is –10 dBm. The sleeve antenna, which is known as omni-directional antenna, is used for the transmit and receive antennas. The antenna hight is 1.2 m at both transmitter and receiver sites. We use OFDM (Orthogonal Frequency Division Duplexing) signal which is incorporated in Wireless LAN systems. The number of sub-carriers and length of guard interval are 56 and 1.6 μS, respectively. We obtained the channel matrix by using long preamble on OFDM signals with the interval of 0.152 ms.

In this measurement, the MIMO channels are measured when a person moves on Course A or B, respectively. The total measurement time were 5 and 3 seconds for Course A and B, respectively. The antenna positions for Tx and Rx in this measurement are shown in Fig. 1. The element spacing d_{Tx} at the transmitter site is set to be 1, 4, 8, and 16 λ, respectively. To evaluate the influence on the element spacing between Rx1 and 2, d_{Rx} at the receiver site in detail, d_{Rx} was changed from 1 to 13 λ with the interval of half wavelength by using a position controller.

4 Effectiveness of MIMO sensor in indoor environment

First, we define threshold values which judge whether the intrusion detection is possible or not. When considering without people in the room, the time correlation regarding $\boldsymbol{H}$ is very close to 1 [3]. On the other hand, we have to judge whether the intrusion is employed or not by using the value which is obtained in Eqn.(4). We evaluate the influence on the time correlation by a gaussian noise. The time correlation considering the gaussian noise ρ_N is represented as,

$$\boldsymbol{H}_{w/n} = \boldsymbol{H}_{wo/n} + \frac{1}{\mathrm{SNR}}\boldsymbol{H}_n \tag{5}$$

$$\rho_H = \frac{\left|\sum_{i=1}^{N}\sum_{j=1}^{M} h_{wo/n,ij}^{*} h_{w/n,ij}\right|}{\sqrt{\sum_{i=1}^{N}\sum_{j=1}^{M} \left|h_{wo/n,ij}\right|^2}\sqrt{\sum_{i=1}^{N}\sum_{j=1}^{M} \left|h_{w/n,ij}\right|^2}} \tag{6}$$

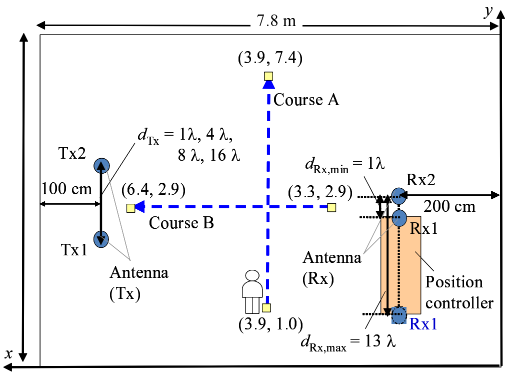

Figure 1: Measurement environment.

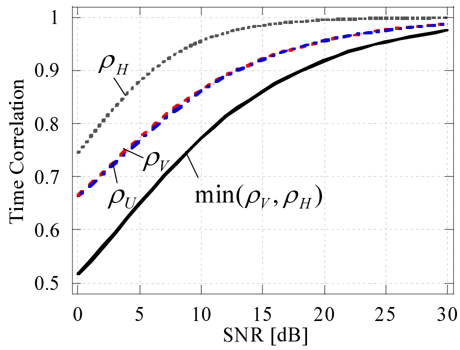

Figure 2: Correlation versus SNR with only gaussian noise.

where $\boldsymbol{H}_{w/n}$ and $\boldsymbol{H}_{wo/n}$ are the channel matrix with/without the thermal noise. $\boldsymbol{H}_n$ is the matrix by the gaussian noise. $h^*_{w/n,ij}$ and $h_{wo/n,ij}$ $(i = 1 \sim N, j = 1 \sim M)$ are components on the channel matrix when considering with/without the thermal noise, respectively.

Fig. 2 shows the correlation characteristics versus SNR when considering only gaussian noise. We assume i.i.d. channel in Fig. 2. ρ_V and ρ_U are the correlations for transmitting and receiving eigenvectors. $\min(\rho_V, \rho_U)$ denotes the results for the proposed method. As can be seen in Fig. 2, the correlation is reduced due to gaussian noise when the SNR is very small. On the other hand, the correlation is greater than 0.9 when considering SNR $\geq$ 20 dB. We use the value of correlation for each SNR as the threshold value in Fig. 2.

The break-in detection performance is demonstrated based on the measured channel. Fig. 3 denotes the time correlation characteristics when the antenna spacing is 1λ or 4λ. Here, the result is for the course B. The proposed method is applied in MIMO configuration in Fig. 3. The straight line in Fig. 3 denotes the threshold value when SNR = 10 dB for the proposed method. The time correlation regarding a first receiving eigenvector is used in SIMO configuration [1]. As can be seen in this figure, the time correlation by using the proposed method in MIMO configuration is much lower than that by using the conventional method in SIMO configuration. Moreover, the time correlation in the proposed method becomes lower when the antenna spacings for Tx and Rx becomes wider. Hence, it is expected that the distributed antenna configuration can improve the break-in detection performance.

Fig 4 and 5 show the detection probabilities on Course A and B, respectively, when the antenna spacing for Tx is varied. All results on the antenna spacing for Rx, $(d_{Rx} = 1 \sim 13\ \lambda)$ are used. As can be seen in these figures, high detection probability in much lower SNR is obtained using MIMO configuration compared to SIMO configuration for each course. It is shown that required SNR for 90 % detection by the MIMO configuration is 5 to 13 dB lower compared to the SIMO configuration. When considering the antenna spacing in MIMO configuration, the detection probability can be improved by wider antenna spacing. Hence, It is shown that the distributed antenna configuration is effective in enhancing detection probability without increasing the transmitting power. On the other hand, the improvement

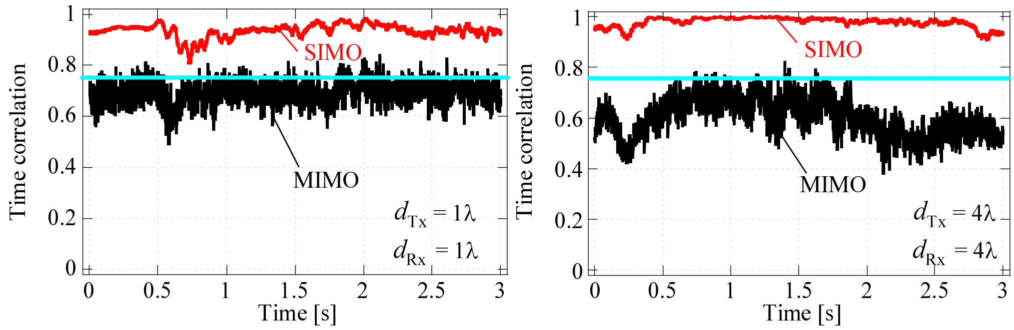

Figure 3: Time correlation versus observation time (Course B).

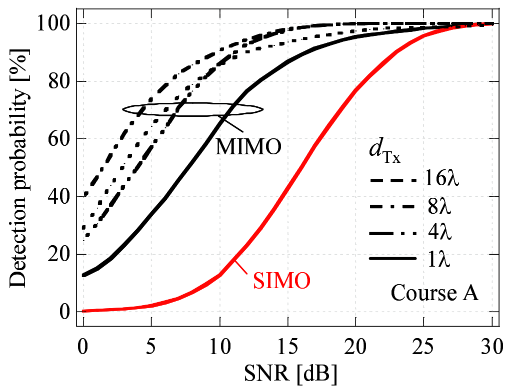

Figure 4: Detection probability vs. SNR (Course A).

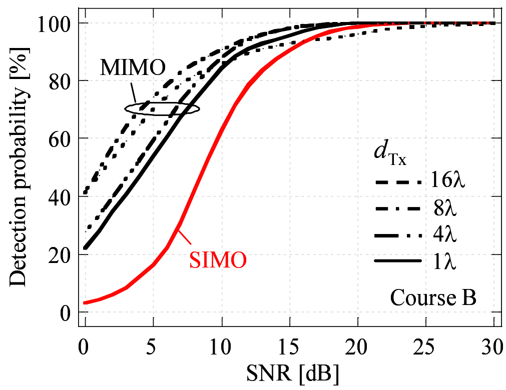

Figure 5: Detection probability vs. SNR (Course B).

regarding the detection probability is saturated when the antenna spacing is greater equal to 4 λ.

5 Conclusion

In this paper, we proposed the intruder detection method which utilizes the eigenvectors for both transmitter and receiver in MIMO channels. Moreover, we clarified the effectiveness the distributed antenna configuration in an actual indoor propagation environment. We found that the required SNR for 90 % detection by using the proposed method in MIMO configuration is 5 to 13 dB lower compared to the conventional method in SIMO configuration. It is shown that the distributed antenna configuration is effective in enhancing detection probability without increasing the transmitting power.

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