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Passive MIMO Transmission Using Load Modulation

[#]Keisuke Terasaki, Kosuke Kinami, Naoki Honma,
Graduate School of Engineering, Iwate University
4-3-5 Ueda, Morioka, 020-8551, Japan
t2312026@iwate-u.ac.jp

1. Introduction

RFID (Radio Frequency Identification) is a technology for identifying and managing people and goods using small wireless chip called tag. This technology is used in logistics and personal authentication. Passive type RFID using load modulation [1][2] has the advantage that it does not need transmitter in the tag side, but traditional load modulation system using single antenna have disadvantage that it cannot attain high-speed data transmission .

In this paper, a passive MIMO (Multiple-Input Multiple-Output) transmission using load modulation is proposed. In this method, load modulation is applied to the multi-antenna, and a number of signals can be transmitted in parallel. The tag is defined as the multi-antenna that has load impedance, and it can control the reflective wave by switching its load impedance independently. The transmitted signals are estimated from the received signal vector observed at the reader using multi-antenna. The termination impedance pattern of the tag antennas is determined so as that its reflection coefficients are to be distant each other in complex number plane.

In the following part of this paper, the proposed multi-antenna load modulation method is expressed, and numerical results are reported in detail. From the results, it is shown that the passive MIMO transmission using load modulation offers a high-speed data transmission without increasing the number of the transmitters.

2. Proposed multi-antenna load modulation method

In the passive MIMO transmission scheme, the transmitted signals are reflected by the multi-antennas at the tag side, and the reflected wave is received at the receiver. The communication between the reader and the tag is achieved by the load modulation. In the load modulation, the amplitude and phase of the reflected wave are controlled by switching the load impedances that are connected to the tag antennas.

Figure 1 shows a system model of proposed passive MIMO transmission scheme. Two cases of the reader antenna configuration, which are mono-static and bi-static structures, are considered. Figure 1 (a) shows the mono-static structure, where the transmitting and receiving antennas to be collocated at the reader, and (b) shows the bi-static structure, where the transmitting and receiving antennas at the reader are placed far apart. In this model, T, P, and R represent the transmitting, tag, and receiving ports, respectively. $\boldsymbol{S}_{RT}$, $\boldsymbol{S}_{RP}$, $\boldsymbol{S}_{RT}$ are the scattering matrices that denote the channels among T, P, and R ports. $\boldsymbol{S}_{TT}$, $\boldsymbol{S}_{PP}$ are the scattering matrices that denote the reflection and coupling coefficients at transmitting antenna and tag antenna, respectively. The reflection coefficient $\boldsymbol{\Gamma}$ of the termination loads is given as

$$\boldsymbol{\Gamma} = \mathbf{diag}\left(\frac{z_1 - z_0}{z_1 + z_0}, \ldots, \frac{z_m - z_0}{z_m + z_0}\right), \qquad (1)$$

where m is the number of the tag antennas, z_1, …, z_m are the load impedance values of the tag antennas #1, …, #m, respectively, and z_0 is the reference impedance.

In case of the mono-static structure, the apparent scattering matrix, $\boldsymbol{S'}_{TT}$, observed at the reader can be obtained from scattering matrices and reflection coefficient as

$$\boldsymbol{S}'_{TT} = \boldsymbol{S}_{TT} - \boldsymbol{S}_{TP}\left(\boldsymbol{S}_{PP} - \boldsymbol{\Gamma}^{-1}\right)^{-1}\boldsymbol{S}_{PT}\,. \quad (2)$$

In case of the bi-static structure, the apparent scattering matrix, $\boldsymbol{S'}_{RT}$, observed at the reader can be obtained as

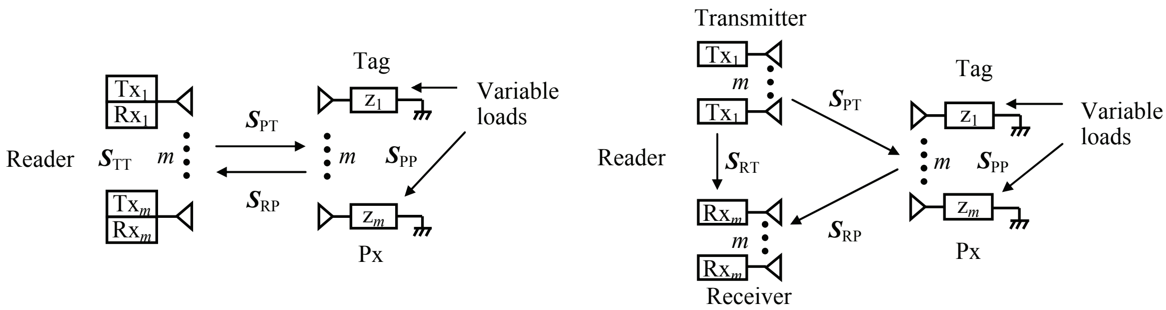
$$\boldsymbol{S}'_{RT} = \boldsymbol{S}_{RT} - \boldsymbol{S}_{RP}\left(\boldsymbol{S}_{PP} - \boldsymbol{\Gamma}^{-1}\right)^{-1}\boldsymbol{S}_{PT} \quad (3)$$

Therefore, the received signals vector for the mono-static structure $\boldsymbol{y}_{mono}$, and for the bi-static structure $\boldsymbol{y}_{bi}$ can be obtained as

$$\boldsymbol{y}_{mono} = \boldsymbol{S}'_{TT}\boldsymbol{x} + \boldsymbol{n} \quad (4)$$

$$\boldsymbol{y}_{bi} = \boldsymbol{S}'_{RT}\boldsymbol{x} + \boldsymbol{n}\,, \quad (5)$$

respectively, where $\boldsymbol{x}$ is the transmitting signal from the reader and $\boldsymbol{n}$ is the noise vector. In order to maximize the power delivered to the tag antenna, the transmitting beam-forming is used in this study. Though the transmitted signal is not a modulated one but just a continuous wave, the weight, $\boldsymbol{x}$, is the first eigenvector calculated from $\boldsymbol{S}_{PT}^{H}\boldsymbol{S}_{PT}$. The simulation of load modulation was carried out by using the above formula. The termination impedance pattern of the tag antennas is determined so as that its reflection coefficients are to be distant each other in complex number plane. For example, when transmission rate is 2 Bits/symbol/tag-antenna, the termination impedance is switched among 0, – 50*j*, 50*j*, ∞.



(a) Mono-static structure (b) Bi-static structure

Fig. 1 System model of passive MIMO transmission

3. Simulation conditions

Both the transmitting receiving antennas have dipole antenna elements and the frequency is 2.4 GHz. For the bi-static structure, the distance between the transmitting and receiving antennas is 1 m. the reader antenna element spacing is 1 λ , the tag antenna element spacing is 0.25 λ , respectively. The transmitter and the tag and the receiver have the same number of antennas *m*, and three patterns, i.e. *m* = 2, 4, 6, are evaluated. The noise is assumed to be zero-mean Gaussian white. The channel between the reader and the tag antennas is calculated by ring model. In this ring model, 10 scatterers are distributed on the horizontal plane around each array antenna, and ring size is set to 100 m. MLD (Maximum Likelihood Detection) is used as a decoding algorithm at the reader. A symbol length is defined as a period, where the certain termination combination is given and kept.

4. Simulation results

Figure 2 (a), (b) shows example of the constellation of the received signals for the bi-static structure. The number of the antenna, *m*, is 2, and SNR is 20 dB. The termination impedance at the tag antennas is switched among 4 values, i.e., 0, – 50*j*, 50*j*, ∞. The circle is the ideal received signal point, the cross is the received signal point that includes the noise, and the square is the transmitted carrier signal. These figures indicate number of the ideal received signal points are 16, that is, the transmission rate of 4 Bits/symbol can be achieved.

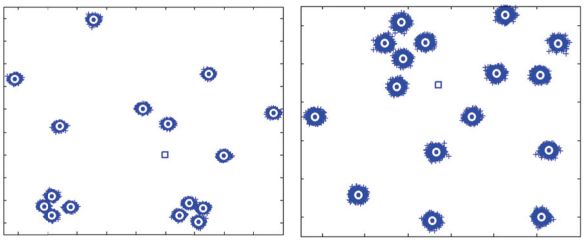
Table 1, 2 shows the threshold noise power when BER (Bit Error Rate) becomes 10^{-2} versus the transmission rate for SISO (Single-Input Single-Output) and MIMO, respectively. Here, the number of the tag antenna, m, is 2, the transmission power is 20 dBm, and the distance between the reader and the tag antennas is 3 m. The result of the SISO scheme that is conventional method is also shown for comparison. The performances of the mono-static structure and the bi-static structure are compared for SISO and MIMO schemes. From this result, proposed method is more effective if the required transmission rate is higher. When the transmission rate is 4 Bits/symbol, in case of the mono-static structure, the threshold noise power that achieve BER = 10^{-2} is improved by 4.7 dB compared with that in SISO. In case of the bi-static structure, the threshold noise power that achieve BER = 10^{-2} is improved by 8.5 dB compared with that in SISO. From these results, the required transmitting power can be reduced by 3.8 dB in the bi-static structure compared to that in the mono-static structure.

Figure 4 shows CDF (Cumulative Distribution Function) of the channel gain in case of the mono-static structure and the bi-static structure. The transmission rate is 4 Bits/symbol, and m = 2. The channel gain of the mono-static structure and bi-static structure is can be obtained as,

$$G_{mono} = \left\| \boldsymbol{S}_{TP} \left(\boldsymbol{S}_{PP} - \boldsymbol{\Gamma}^{-1} \right)^{-1} \boldsymbol{S}_{PT} \right\|_F \quad (6)$$

$$G_{bi} = \left\| \boldsymbol{S}_{RP} \left(\boldsymbol{S}_{PP} - \boldsymbol{\Gamma}^{-1} \right)^{-1} \boldsymbol{S}_{PT} \right\|_F , \quad (7)$$

respectively. In this result, it is found that the change of the channel gain according to the randomness of channels for the mono-static structure is larger than that for the bi-static structure, and the channel gain in the 10 percent value of the CDF for the bi-static structure is improved 0.9 dB compared with that for the mono-static structure. Therefore, the average BER for the mono-static structure can be deteriorated by the influence of the undesired environment. Therefore, the bi-static structure is used in the following discussion.



(a) Received antenna 1 (b) Received antenna 2

Fig. 2 Constellation of received signal

Table. 1 Threshold noise power versus transmission rate for SISO

Rate [Bits/symbol]	SISO (mono-static)	SISO (bi-static)
2	-84.37	-84.11
4	-93.71	-93.07
6	-100.21	-99.93
8	-106.24	-106.04
12	-118.05	-117.71

Table. 2 Threshold noise power versus transmission rate for MIMO

Rate [Bits/symbol]	MIMO (mono-static)	MIMO (bi-static)
2	-86.29	-81.96
4	-88.98	-84.6
6	-92.95	-88.89
8	-96.78	-93.57
12	-104.29	-100.46

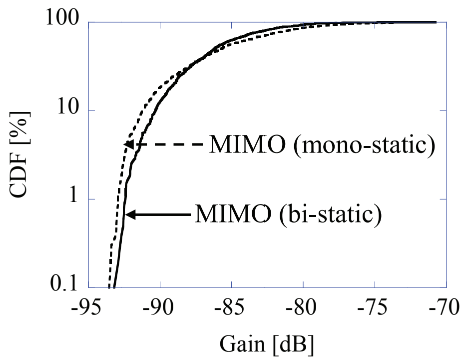


Fig. 4 CDF of channel gain

Figure 5 shows the threshold noise power versus the number of the antennas at the tag. Here, the threshold is defined as the noise power that yields BER= 10^{-2}. The number of the reader and tag antenna is identically given as m, and m = 1 represents the SISO scheme. It can be seen that the many more the number of the antenna elements, m, becomes, the higher the noise threshold becomes. This means that MIMO scheme can extend the communication distance. From this result, when the transmission rate is 12 Bits/symbol, it is found that the threshold noise power with m = 2 is alleviated by 17 dB, and the threshold noise power with m = 6 is alleviated by 32 dB compared to that with m= 1, respectively.

Figure 6 shows the BER characteristics versus the distance between the reader and tag antennas when the various transmission powers, i.e., 10, 20, and 30 dBm, are given. The BER characteristics are calculated by assuming the free space propagation loss. The number of antenna, m, is 2, and the noise power is −100 dBm, and the transmission rate is 4 Bits/symbol. The achievable distance in the proposed method is up to 4.1 m when the transmission power is 10 dBm. The achievable distance is up to 13 m when the transmission power is 30 dBm. From this result, it is found that the proposed passive MIMO scheme yields not only high data rate but also long communication distance.

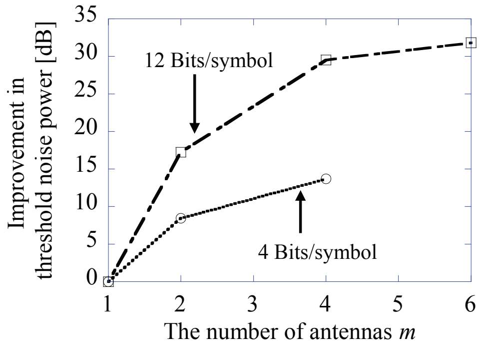


Fig. 5 Improvement in threshold noise power versus the number of antennas

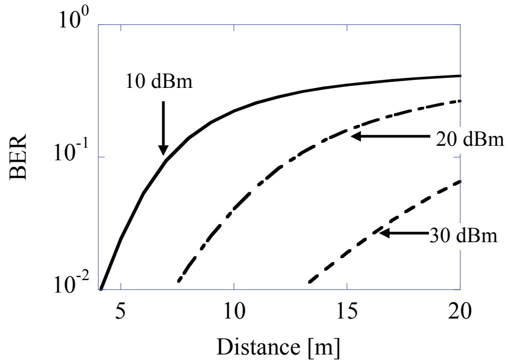


Fig. 6 Distance versus BER

5. Conclusion

This paper has proposed passive MIMO transmission using load modulation. In this method, load modulation is applied to the multi-antenna, and a number of signals are transmitted in parallel. When the transmission rate is 4 Bits/symbol, the threshold noise power when BER = 10^{-2} is improved by 4.7 dB compared to SISO for the mono-static structure, and is improved by 8.5 dB for the bi-static structure. It is found that the required power can be reduced by 3.8 dB for the bi-static structure compared to that for the mono-static structure. When the transmission rate is 12 Bits/symbol, the threshold noise power with m = 2 is alleviated by 17 dB, and the threshold noise power with m = 6 is alleviated by 32 dB compared to that with m= 1, respectively. It is found that the many more the number of the antenna elements becomes, the higher the noise threshold becomes. These results support the passive MIMO transmission using load modulation allows high-speed data transmission without using the transmitter at the tag antenna.

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