IEICE Communications Express, Vol.4, No.8, 258–263

Fast demodulation method for passive MIMO communication by using beam-forming at receiver

Ryota Takahashi[1], **Keisuke Terasaki**[1], **Kentaro Murata**[2], **Naoki Honma**[1a)], **and Yoshitaka Tsunekawa**[1]

[1] *Graduate School of Engineering, Iwate University, 4–3–5 Ueda, Morioka, 020–8551, Japan*

[2] *Graduate School of Engineering, National Defense Academy, 1–10–20, Hashirimizu, Yokosuka, Kanagawa, 239–8686, Japan*

a) *honma@iwate-u.ac.jp*

Abstract: In this letter, we propose the demodulation method to improve the complexity of demodulation in passive MIMO (Multiple-Input Multiple-Output) scheme. This scheme uses the multiple antennas at both reader and RFID (Radio Frequency Identification) tag to increase the data-rate, but the complexity of MLD (Maximum Likelihood Detection), which is used as demodulation algorithm, increases exponentially with the number of antennas. The proposed method divides tag antennas into two groups that do not interfere each other by decoupling tag antenna groups using 180-degree hybrids at tag side and beam-forming at receiver side. Individual demodulation for each group improves the complexity of MLD significantly. Simulation results show the proposed method can reduce the complexity of MLD with degrading slight BER (Bit-Error-Rate) performance. The results reveal the proposed method is effective in reducing demodulation complexity of passive MIMO transmission even when the number of tag antennas is increased.

Keywords: MIMO, RFID, load modulation, beam-forming, MLD

Classification: Antennas and Propagation

References

[1] A. Juels, "RFID security and privacy: a research survey," *IEEE J. Sel. Areas Commun.*, vol. 24, no. 2, pp. 381–394, Feb. 2006. DOI:10.1109/JSAC.2005.861395

[2] V. Stanford, "Pervasive computing goes the last hundred feet with RFID systems," *IEEE Pervasive Comput.*, vol. 2, no. 2, pp. 9–14, Feb. 2003. DOI:10.1109/MPRV.2003.1203746

[3] V. Chawla and D. S. Ha, "An overview of passive RFID," *IEEE Commun. Mag.*, vol. 45, no. 9, pp. 11–17, Sep. 2007. DOI:10.1109/MCOM.2007.4342873

[4] K. Terasaki, K. Kinami, and N. Honma, "Passive MIMO transmission using load modulation," 2012 Int. Symp. Antennas Propagat. (ISAP 2012), Electric Proc. of ISAP 2012, POS2-27, Oct. 2012.

DOI: 10.1587/comex.4.258
Received July 6, 2015
Accepted July 13, 2015
Published August 10, 2015

[5] K. Terasaki and N. Honma, "Feasible load modulation technique using multiple antenna systems," *Electron. Lett.*, vol. 48, no. 18, pp. 1090–1091, Aug. 2012. DOI:10.1049/el.2012.1817
[6] A. van Zelst, R. van Nee, and G. A. Awater, "Space division multiplexing (SDM) for OFDM systems," IEEE VTC 2000-Spring, Japan, vol. 2, pp. 1070–1074, May 2000. DOI:10.1109/VETECS.2000.851289
[7] J. C. Coetzee and Y. Yu, "Port decoupling for small arrays by means of an eigenmode feed network," *IEEE Trans. Antennas Propag.*, vol. 56, no. 6, pp. 1587–1593, Jun. 2008. DOI:10.1109/TAP.2008.923301
[8] K. Murata, H. Morishita, N. Honma, K. Nishimori, and D. M. Klymyshyn, "Analog-digital hybrid eigenmode transmission for massive short-range MIMO," 2014 IEEE International Workshop on Electromagnetics, vol. 2, pp. 223–224, Aug. 2014. DOI:10.1109/iWEM.2014.6963717

1 Introduction

RFID (Radio Frequency Identification) is the technology to identify human and materials by using radio frequency tags [1]. For example, it is used electronic money, travel card, employee ID card, and so on [2]. Especially, passive RFID gets a lot of attention in the RFID scheme, because passive RFID tags do not need the power supply [3]. Due to its convenience, the passive RFID is expected to be used for the logistic management, and so on. However, passive RFID has a problem that the transmission speed between reader and tags is not sufficiently high if they need to transfer a large data, such as photo images, video, and so on [4].

To increase the data rate in passive RFID communication, the passive MIMO (Multiple-Input Multiple-Output) technique has been proposed [4, 5]. Passive MIMO uses the multiple antennas at both reader and tag sides, and also uses multi-level load modulation by variable impedance. The tag data can be parallelly transmitted to the reader antennas. At the reader side, the multiple load modulated signals are observed, and they are decoded by using MLD (Maximum Likelihood Detection) [6]. In this scheme, parallel data transmission is realized without extending frequency resources. When mutual coupling at the tag side is existed, the load modulated signals are modulated again by other tag. Therefore, the other demodulation scheme, such as eigenmode beam-forming, cannot realize the parallel data transmission. MLD can decode the multiple signals from the tag antennas even in this case. But, the complexity of MLD exponentially increases with the number of antennas.

In this letter, the demodulation method that significantly decreases the complexity of MLD by introducing analog signal processing is proposed. The analog signal processing at the tag side is realized by using 180-degree hybrid and this decouples the mutual coupling between two antenna groups that are configured symmetrically to each other [7, 8]. This scheme enables the reader receiver to demodulate the signal sets corresponding two antenna groups individually by using the digital beam-forming. Therefore, the complexity of MLD is significantly reduced since the total number of the signals for demodulation is reduced. The effectiveness of proposed method is evaluated numerically.

DOI: 10.1587/comex.4.258
Received July 6, 2015
Accepted July 13, 2015
Published August 10, 2015

2 Group demodulation method by using beam-forming

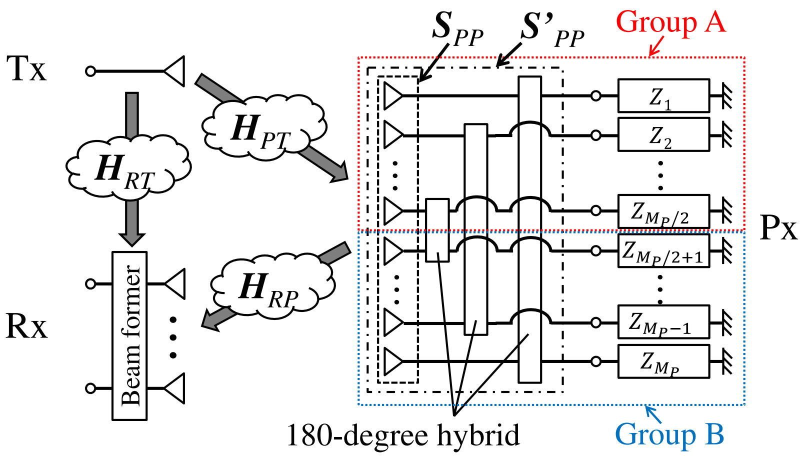


Fig. 1. Proposed system model

Fig. 1 shows the proposed system model of group demodulation method. $\boldsymbol{H}_{RT}$ represents the propagation channel from reader-transmitter (Tx) to reader-receiver (Rx), and $\boldsymbol{H}_{PT}$, $\boldsymbol{H}_{RP}$ are respectively represented the propagation channel from Tx to Px and from tags (Px) to Rx. $\boldsymbol{S}_{PP}$ is the scattering matrix representing the S-parameter of tag antenna. $\boldsymbol{S}'_{PP}$ is the scattering matrix including 180-degree hybrids. 180-degree hybrids can decouple two groups of the tag antennas, when the structure is symmetric and the number of antennas is even [7, 8]. In case of configuring tag antennas symmetrically, $\boldsymbol{S}'_{PP}$ is represented as

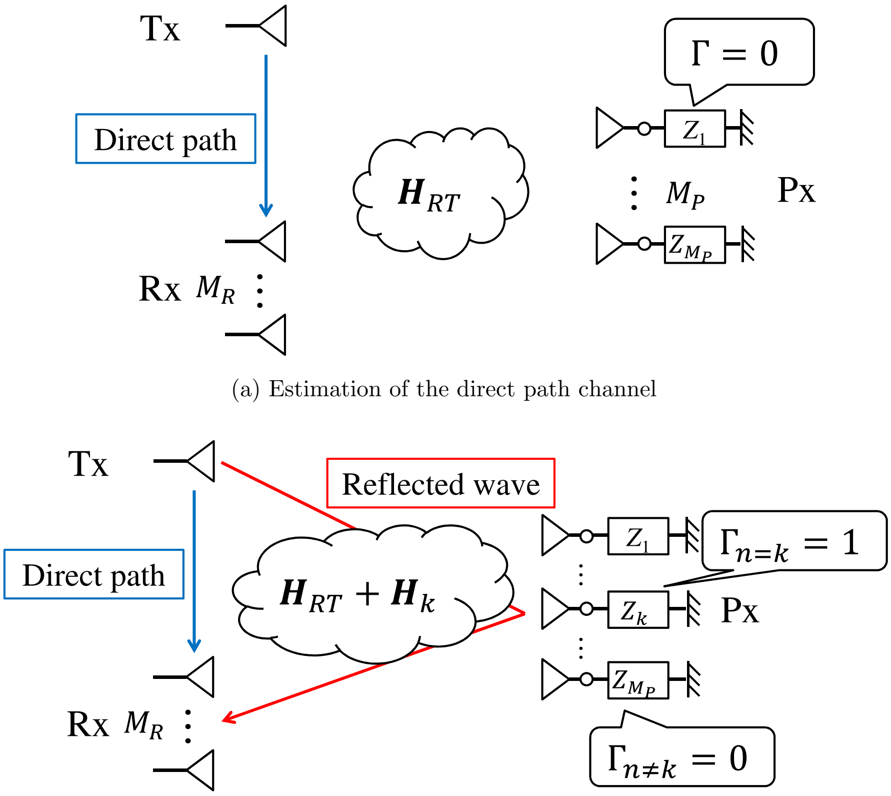
$$\boldsymbol{S}'_{PP} = \begin{pmatrix} \boldsymbol{S}_{PP_{1\sim M_P/2}} & \boldsymbol{O} \\ \boldsymbol{O} & \boldsymbol{S}_{PP_{M_P/2+1\sim M_P}} \end{pmatrix} \tag{1}$$

where $\boldsymbol{S}_{PP_{1\sim M_P/2}}$ is the scattering matrix representing the S-parameter which is composed of tag$1, \ldots, M_P/2$, and $\boldsymbol{S}_{PP_{M_P/2+1\sim M_P}}$ is composed of tag$M_P/2+1, \ldots, M_P$. $\boldsymbol{O}$ is zero matrix. From (1), two antenna groups are isolated completely. Reader can discretely demodulate the signal sets corresponding to two groups by beam-forming. Since the number of the antennas in each group can be reduced by half, the complexity of MLD is reduced significantly compared with that of the conventional method.

Fig. 2(a) shows an estimation method of the channel via Px, $\boldsymbol{H}_k$. M_P is the number of tag antennas, M_R is the number of receiver antennas. Proposed method needs the channel via Px for beam-forming at reader, but Rx can only observe the sum of the direct signal and reflected signal via Px. Therefore, the reader needs to estimate the channel from Px to Rx by excluding the direct path. Fig. 2(a) shows the way to estimate the direct path channel. Reference impedance terminates each tag antennas to suppress the reflection from tag, that is, the reflection coefficient is 0. Therefore, only the direct path channel, $\boldsymbol{H}_{RT}$, can be observed at the reader. Fig. 2(b) shows estimation of the sum of direct and reflected path channel. In order to observe the channel components, one of the reflection coefficients of the tag antenna terminations is set to 1 (open) and the rest of the other terminations are set

DOI: 10.1587/comex.4.258
Received July 6, 2015
Accepted July 13, 2015
Published August 10, 2015

IEICE Communications Express, Vol.4, No.8, 258–263



(a) Estimation of the direct path channel

(b) Estimation of the sum of direct and reflected path

Fig. 2. Channel estimation

to 0. $\boldsymbol{H}_k$ is the reflected path channel when the termination condition of the tags is represented by $\boldsymbol{\Gamma}_k$, which is given as

$$\boldsymbol{\Gamma}_k = \mathrm{diag}(0\ldots0, \gamma_{\mathrm{open}\ k}, 0\ldots0) \tag{2}$$

where $\gamma_{open\ k}$ is the reflection coefficient when the load impedance of k-th port is opened. The sum of the direct and reflected channels, $\boldsymbol{H}$, which is observed at receiver, is represented by

$$\boldsymbol{H} = \boldsymbol{H}_{RT} + \boldsymbol{H}_{RP}(\boldsymbol{S}'_{PP} - \boldsymbol{\Gamma}_k^{-1})^{-1}\boldsymbol{H}_{PT} \tag{3}$$

where $\boldsymbol{H}_{PT}$, $\boldsymbol{H}_{RP}$ is the channels from Tx to Px and from Px to Rx, respectively. Since $\boldsymbol{H}_{RT}$ has been estimated, $\boldsymbol{H}_k$ via tag$k$ can be calculated by eliminating $\boldsymbol{H}_{RT}$ from (3) and represented as

$$\boldsymbol{H}_k = \boldsymbol{H}_{RP}(\boldsymbol{S}'_{PP} - \boldsymbol{\Gamma}_k^{-1})^{-1}\boldsymbol{H}_{PT}. \tag{4}$$

The reader can divide and demodulate the signal sets corresponding two antenna groups by beam-forming. For example, when the reader demodulates the signals from Group A, which is composed of tag$1, \ldots, M_P/2$, null beam-forming that directs null directivity to Group B, which is composed of tag$M_P/2+1, \ldots,$ M_P. The beam-forming weight can be calculated from the singular value decomposition (SVD) of the channel between the reader and Group B tags as,

$$[\boldsymbol{H}_{M_P/2+1}, \ldots, \boldsymbol{H}_{M_P}] = [\boldsymbol{U}_B, \tilde{\boldsymbol{U}}_B][\boldsymbol{S}_B, 0]\boldsymbol{V}_B^H \tag{5}$$

where $\boldsymbol{U}_B$ and $\tilde{\boldsymbol{U}}_B$ represent signal and noise space eigenvectors, respectively, and $\boldsymbol{U}_B$ is used for receiving signals from Group A since no interference from Group B

DOI: 10.1587/comex.4.258
Received July 6, 2015
Accepted July 13, 2015
Published August 10, 2015

IEICE Communications Express, Vol.4, No.8, 258–263

is received by using $\widetilde{U}_B$ at the reader. Similarly, the signal sets of Group B can be demodulated in the same manner. Therefore, the proposed method can demodulate the signal of each group discretely.

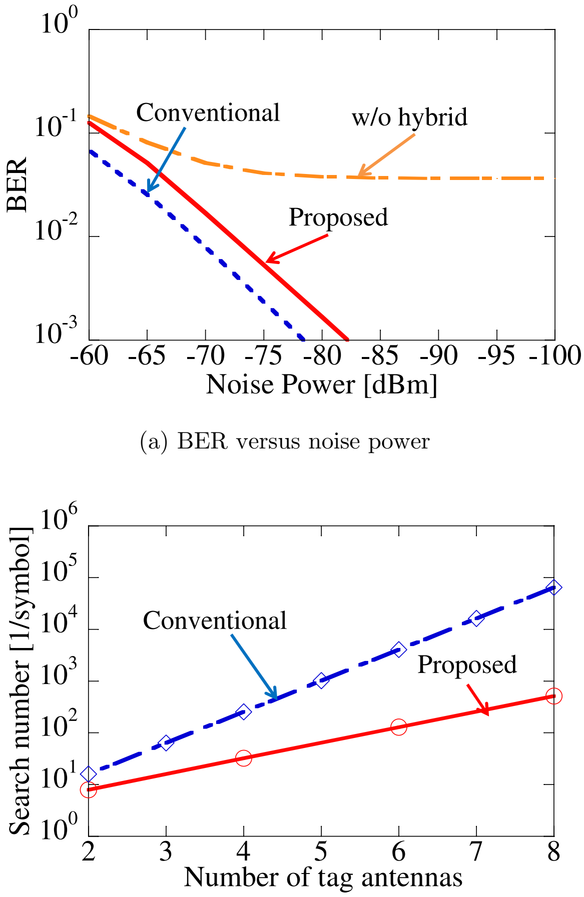
3 Simulation

3.1 Simulation setup

All the antenna elements in the simulation are half-wave dipoles for simplicity. The frequency is 2.47 GHz, the distance between reader and Px is 1 m, and the distance between Tx and Rx is 1 m too. The tag element spacing is 0.5 wavelength, and the receiver element spacing is 1.0 wavelength. The transmission power is 20 dBm, and the noise is assumed to be zero-mean Gaussian white. The propagation channel is calculated by Clarke's model.

3.2 Simulation results

Fig. 3(a) shows BER (Bit-Error-Rate) versus noise power, where the M_{P} and M_{R} are 8. From this figure, it is clear that proposed method needs 180-degree hybrid to demodulate the received signals accurately. The deterioration in the curve, 'w/o hybrid', is caused by the interference between two antenna groups, and the combination of the beam-forming and 180-degree hybrid successfully suppresses



(a) BER versus noise power

(b) Complexity of MLD versus number of tag antennas

Fig. 3. Simulation results

© IEICE 2015
DOI: 10.1587/comex.4.258
Received July 6, 2015
Accepted July 13, 2015
Published August 10, 2015

IEICE Communications Express, Vol.4, No.8, 258–263

this interference. Also, proposed method causes degradation in BER performance compared with the conventional method. Since the proposed method uses null beam-forming, the SNR is slightly degraded.

Fig. 3(b) shows the complexity of MLD versus the number of tag antennas in case of QPSK modulation. The result shows proposed method significantly improves the complexity of MLD. For example, when the number of tag antennas is 8, the search number of conventional method is 65536 per symbol to demodulate all signals from the tags, whereas the search number of proposed method is 256 per symbol. The proposed method becomes more effective when the number of the antennas is increased because the complexity of MLD increases exponentially with the number of tag antennas.

4 Conclusion

This letter has proposed the method to reduce the complexity of MLD in passive MIMO by combining the analog signal processing and digital beam-forming. When the number of the antennas at both reader and tag sides is 8, proposed method can reduce the complexity of MLD to 1/128 of conventional method, and the effectiveness increases exponentially with the number of antennas. These results show that proposed method is effective in reducing the complexity of MLD in passive MIMO communication.

Acknowledgments

This research was partially supported by JSPS KAKENHI (25709030).

DOI: 10.1587/comex.4.258
Received July 6, 2015
Accepted July 13, 2015
Published August 10, 2015