MMSE Based Interference Cancellation and Beamforming Scheme for Signal Transmission in IoT

Xin Su[1], YuPeng Wang[2](✉), Chang Choi[3], and Dongmin Choi[4]

[1] Changzhou Key Laboratory of Robotics and Intelligent Technology, College of IoT Engineering, Hohai University, Changzhou, China
leosu8622@163.com

[2] College of Electronic & Information Engineering, Shenyang Aerospace University, Shenyang, China
ypwang@sau.edu.cn

[3] Department of Computer Engineering, Chosun University, Gwangju, Korea
enduranceaura@gmail.com

[4] Division of Undeclared Majors, Chosun University, Gwangju 61452, Korea
jdmcc@chosun.ac.kr

Abstract. Due to the application nature of Internet of Things, various different kinds of devices will be connected to the network. To increase the access opportunity, a spreading based signal transmission technique is proposed to be used in the signal transmission of IoT. To alleviate the effects of rich scattering transmission environment and interferences from other devices, MMSE based interference cancellation combined with the receive beamforming is proposed in this paper. Through simulation, we observe that the proposed algorithm is outperforms the conventional spreading transmission schemes and is suitable for the transmission environment of IoT.

Keywords: IoT · Interference cancellation · Receive beamforming · MMSE

1 Introduction

As the rapid development of science and technology, the world is becoming smarter and smarter. In the smart word, people have extended their connection needs from the hand phone, PDA, notebook to the smart wearable devices, smart transportations, smart environment, and etc. Eventually, all the network world, physical world, and social world which are related to our daily life will be merged together to form a highly inter-connected smart world. The IoT (Internet of Things) technique which is considered as the corner stone of the future smart world, is continuously taking huge attentions from academia and industry [1–3].

Currently, the research around IoT focuses on the high layer issues, networking issues, and energy harvesting issues. Maria Gorlatova proposed a method which evaluates the energy recovery efficiency based on the trajectory of acceleration speed and applied the related algorithm in the design of energy recuperator [4]. Xiaosen Liu proposed an energy harvesting method based on 0.18 mm COMS [5]. Zhiqui Chen

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proposed to utilize the device's remaining energy in the routing method to optimize the transmission energy efficiency [6]. However, little research was done on the physical layer signal transmission. In this paper, we introduce the concept of spreading and smart antenna to mitigate the effects of rich scattering transmission environment and interference among IoT users.

The remaining part of this paper is as follows. In Sect. 2, we formulate the physical layer transmission problem considered in this paper. The proposed IoT signal transmission technique is described in Sect. 3. The evaluation results are given in Sect. 4. Conclusions are drawn in Sect. 5.

2 Problem Formulation

The IoT is composed of many different kinds of devices to satisfy people's various daily needs. In order to alleviate the communication coordination environment and provide more medium access opportunities, the concept of spectrum spreading is introduced in this paper. By selecting the proper pseudo-random sequence such as m-sequence or gold sequence, the interference between difference devices can be mitigated.

The transmitted signal of the k^{th} user after the spreading operation $x_k(t)$ is shown in (1).

$$x_k(t) = \sqrt{E_k} g_k(t) b_k(t) \tag{1}$$

where $\sqrt{E_k}$ is the amplitude of the transmitted signal; $g_k(t)$ is the pseudo-random sequence to spread the transmitted signal; $b_k(t)$ is the transmitted data symbol;

After de-spreading operation, the k^{th} user's received signal is as

$$\begin{aligned} y_k(t) = {} & h_k \frac{1}{N} \sum g_k(t) A_k(t) g_k(t) b_k(t) \\ & + \sum_{j=1, j \neq k}^{K} h_{j,k} g_k(t) A_k(t) g_k(t) b_k(t) \\ & + n_k(t) \end{aligned} \tag{2}$$

where h_k represents the channel attenuation; $h_{j,k}$ represents the interfering channel attenuation. The first part of the (2) represents the desired received signal and the second part represents the interference from other devices.

3 Proposed MMSE Based IoT Transmission Technique

In this paper, we utilized the minimum mean square error (MMSE) criterion to mitigate the effects of channel attenuation and interference. Firstly, we adopt the MMSE multi-user detection method to eliminate the interference from other users. Then, MMSE based receive beamforming technique is used to obtained the directivity gain of the antenna array.

3.1 MMSE Based Interference Cancellation

To minimize the mean square error, the MMSE based interference cancellation method is to find a optimum weight $\mathbf{L}_{mmse}$, which satisfies (3) [7].

$$\mathbf{L}_{MMSE} = \arg\min_{L}\left\{E\|\mathbf{b} - \mathbf{L}\mathbf{y}\|^2\right\} \tag{3}$$

To make $\frac{d}{dL}[E\|\mathbf{b} - \mathbf{L}\mathbf{y}\|^2] = 0$, we obtain

$$\mathbf{L}_{MMSE} = [\mathbf{R} + \sigma^2\mathbf{A}^{-\mathbf{1}}]^{-1} \tag{4}$$

where $\mathbf{R}$ is the cross-correlation matrix of the pseudo-random sequence; $\mathbf{A} = diag(\sqrt{E_1}, \sqrt{E_2}, \ldots, \sqrt{E_K})_{KxK}$; σ^2 is the variance of AWGN noise.

3.2 MMSE Based Receive Beamforming

To minimize the effects of channel attenuation, smart antenna technique is adopted at the receiver side to obtain the temporal and spatial focusing property, which is provided by the directivity gain of the antenna array. In the proposed algorithm, MMSE based weight calculation method is used. The cost function to be minimized is similar as (3) [8].

$$\mathbf{W}_{MMSE,k} = \arg\min_{\mathbf{W}}\left\{E\|\mathbf{b} - \mathbf{W}\mathbf{y}'_k\|^2\right\} \tag{5}$$

where $\mathbf{y}'_k$ is the output matrix after the MMSE based interference cancellation of the k^{th} user.

Solving (5) gives the expression for the optimum weights based on MMSE for the k^{th} user as (6)

$$\mathbf{W}_{MMSE,k} = \mathbf{R}^{-1}_{y'_k y'_k}\mathbf{r}_{y'_k d} \tag{6}$$

where $\mathbf{R}_{y'_k y'_k}$ is the covariance matrix of the k^{th} user's received signal after the interference cancellation; $\mathbf{r}_{y'_k d}$ is the cross correlation matrix between the signal y'_k and pilot signal d.

Figure 1 shows the detailed structure of the proposed signal transmission technique.

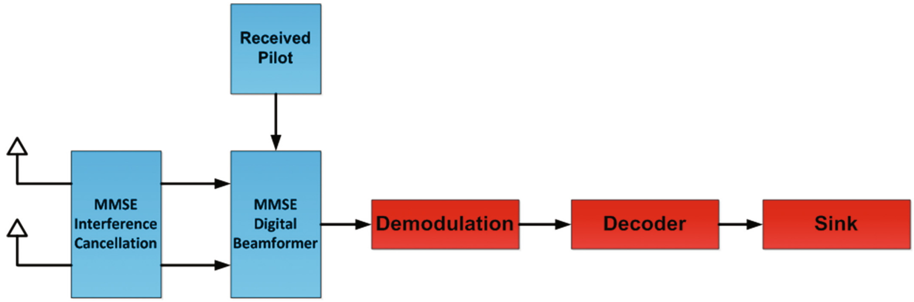

Fig. 1. Detailed signal processing procedure of the proposed algorithm.

4 Performance Evaluation

4.1 Simulation Parameters

In this section, we evaluate the proposed algorithm by the Monte-Carlo simulation. To consider the rich scattering transmission environment of IoT, SCM channel model is utilized instead of the normal Rayleigh fading channel. The detailed simulation parameters are shown in Table 1.

Table 1. Detailed simulation parameters.

Parameter	Value
No. of Devices	8
FEC	Convolutional Code
Modulation	QPSK
PN Sequence	M-sequence
Channel Model	SCM
SIR for Interference	0 dB
No. of Antennae	2 for Rx

4.2 Simulation Results

Figure 2 shows the temporal focusing property of the proposed signal transmission technique. To represent the transmission delay, we insert zeros at the beginning of the transmission data sequence. From the figure, we observe only one single peak at the timing where the real data is received, which shows a good timing focusing property.

The BER performance comparison among single antenna spreading transmission without interference cancellation, single antenna spreading transmission with interference cancellation and the proposed algorithm is shown in Fig. 3. From the figure, we found that the spreading operation has little effects in the rich scattering environment, where the received signal suffers heavy channel attenuation and interference. Even though the MMSE based interference cancellation method is used, the signal still have a very high error ratio. However, the proposed algorithm works better than the other

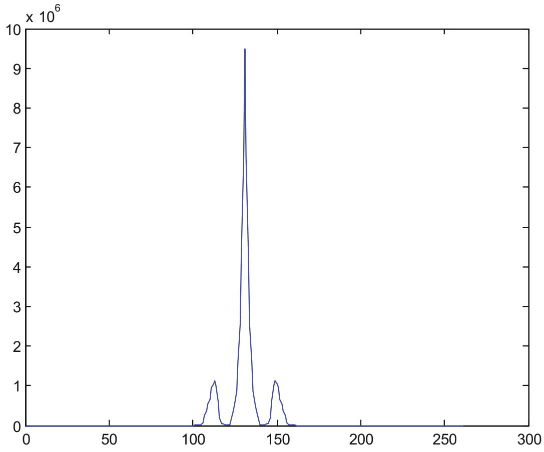

Fig. 2. Temporal focusing property of the proposed algorithm.

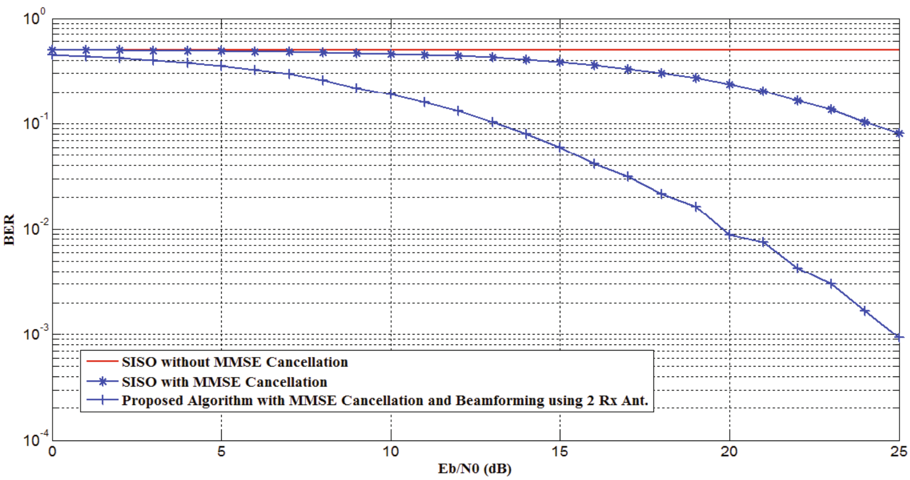

Fig. 3. BER comparison among the proposed algorithm and conventional algorithms

two conventional algorithms due to the cancellation on the interference and elimination on the channel attenuation, the channel attenuation and interference are eliminated.

5 Conclusions

In this paper, we proposed a MMSE based signal transmission scheme to mitigate the effects of rich scattering environment and interference from other devices. From the evaluation results, we found that the proposed algorithm is effective on the interference mitigation and bit error rate reduction.

Although the MMSE based criterion has some application limitations such as the prior knowledge on the channel quality, this can be easily achieved by specific pilot design, which is out of scope of this paper. In addition, most devices served by IoT are an actually low-speed terminal, which means high density pilot insertion is not required to track the channel variations.

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