An Improved Cooperative Communication Scheme for IoT System

Eui-Hak Lee, Jae-Hyun Ro, Hyoung-Kyu Song

Abstract—In internet of things (IoT) system, the communication scheme with reliability and low power is required to connect a terminal. Cooperative communication can achieve reliability and lower power than multiple-input multiple-output (MIMO) system. Cooperative communication increases the reliability with low power, but decreases a throughput. It has a weak point that the communication throughput is decreased. In this paper, a novel scheme is proposed to increase the communication throughput. The novel scheme is a transmission structure that increases transmission rate. A decoding scheme according to the novel transmission structure is proposed. Simulation results show that the proposed scheme increases the throughput without bit error rate (BER) performance degradation.

Keywords—Cooperative communication, IoT, STBC, Transmission rate.

I. Introduction

THE increasing demand for reliability challenges to designers of wireless communication system. The multiple-input multiple-output (MIMO) system is one of the challenges. The MIMO system is to enable reliable communication because of diversity scheme. The leading scheme of diversity scheme is space-time block code (STBC) scheme. STBC scheme can obtain full diversity gain. In order to achieve it, independence of the channel of each stream is necessary. It can be implemented by ensuring sufficient space between the antennas. But, in internet of things (IoT) collaborative scenario, it is not practical that the terminal deploys multiple antennas in limited size. In terminal that uses less power as possible, MIMO system is not appropriate. At the same time to overcome these problems, cooperative communication can obtain diversity gain in one antenna. Cooperative communication which increases the reliability is very effective for struggling multipath fading by sharing antennas [1], [4], [6]. Cooperative communication is a major disadvantage for a throughput. Cooperative communication increases the reliability, but decreases the throughput. It is an important issue. In the recent year, cooperative communication for increasing the throughput was proposed in order to solve this problem [2]. Although the conventional scheme [2] provides high throughput, the scheme that serves higher throughput is needed. In this paper, a novel cooperative communication is proposed to increase transmission rate in relation to the throughput. A system model of the novel cooperative communication is consisted of terminal A,

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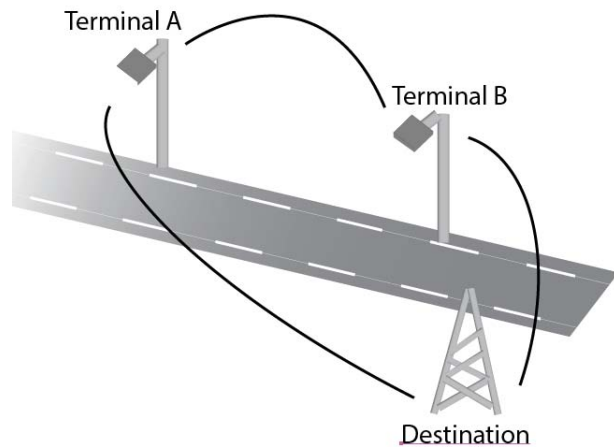
Fig. 1. System model of the proposed scheme

terminal B and destination as Fig. 1. The proposed scheme is that two terminals collaborate in order to communicate.

II. OFDMA Model

An OFDMA system consisting of K orthogonal sub-carriers and P users is considered. Each user is assigned to sub-channel K_p which is a cluster of sub-carriers [2]. In the frequency domain, the data symbol $S^p(k)$ of the p-th user is mapped into following symbol.

$$X^p(k) = \begin{cases} S^p(k), & k \in K_p \\ 0, & \text{otherwise.} \end{cases} \quad (1)$$

Equation (1) is transformed to an OFDMA symbol by the inverse fast Fourier transform (IFFT) during the symbol duration T. And then in the time domain, the n-th sample of the p-th user can be represented as

$$x_n^p = \frac{1}{\sqrt{K}} \sum_{k \in K_p} X^p(k) \exp\left(\frac{j2\pi kn}{K}\right). \quad (2)$$

After adding the cyclic prefix(CP), the transmitted signals by each user go through multi-path fading channel. And then, the received signals at the base-station(BS) can be briefly represented as

$$y_n = \frac{1}{\sqrt{K}} \sum_{p \in P} \sum_{k \in K_p} H^p(k) X^p(k) \exp\left(\frac{j2\pi kn}{K}\right) + \omega_n(k), \quad (3)$$

TABLE I
THE TERMINAL A TRANSMISSION STRUCTURE FOR THE PROPOSED SCHEME

phase	terminal A sub-channel	terminal B sub-channel
1	$\mathbf{X}^A(1)$	
2	$\mathbf{X}^A(2)$	$\mathbf{X}_{DF}^B(1)$
3	$\mathbf{X}^A(3)$	$\mathbf{X}_{DF}^B(2)$
4	$\mathbf{X}^A(4)$	$\mathbf{X}_{DF}^B(3)$
5	$-\left(\mathbf{X}^A(3)\right)^*$	$\left(\mathbf{X}_{DF}^B(4)\right)^*$

TABLE II
THE TERMINAL B TRANSMISSION STRUCTURE FOR THE PROPOSED SCHEME

phase	terminal A sub-channel	terminal B sub-channel
1		$\mathbf{X}^B(1)$
2	$\mathbf{X}_{DF}^A(1)$	$\mathbf{X}^B(2)$
3	$\mathbf{X}_{DF}^A(2)$	$\mathbf{X}^B(3)$
4	$\mathbf{X}_{DF}^A(3)$	$\mathbf{X}^B(4)$
5	$\left(\mathbf{X}_{DF}^A(4)\right)^*$	$-\left(\mathbf{X}^B(3)\right)^*$

where $\omega_n(k)$ is the zero-mean additive white Gaussian noise (AWGN) with variance of σ^2 and $H^p(k)$ is channel coefficient. Equation (3) is transformed by the fast Fourier transform (FFT) from the time domain into the frequency domain. The symbols can be represented as

$$Y(k) = \sum_{p \in P} H^p(k) X^p(k) + W(k). \tag{4}$$

These received signals are equalized through 1-tap equalizer and are decoded. Therefore, the received signals for the proposed cooperation scheme are decoded in the frequency domain.

III. TRANSMISSION SCHEME OF PROPOSED SCHEME

In cooperative communication, terminals and a destination transmit or receive the signal depending on an appointed transmission structure. The conventional transmission structure [2] has 3/4 transmission rate that means 3 symbols transmission per 4 time slots. In this paper, a novel transmission structure is proposed to increase the transmission rate. The proposed transmission structure has 4/5 transmission rate and increases the throughput without decline reliability. In this section, a new transmission structure is proposed in decode and forward (DF) cooperative communication.

It is assumed that the terminal B with the best inter-user channel condition is already selected by using the received signal to noise ratio (SNR) value. The inter-user channel condition means the relative difference of signal's SNR value between the direct channel and the inter-user channel. It is considered that the sub-carrier assignment of two terminals is the same. The basic transmission structures for the proposed scheme are described in Table 1 and Table 2. The terminal A and the terminal B transmit the symbols depending on the proposed transmission structure. In time slot 1, the terminal A transmits the symbol $X(1)$. Because the terminal B doesn't know what symbol is transmitted from the terminal A, the terminal B doesn't transmit any symbol. In time slot 2, the terminal A transmits the symbol $X(2)$. And the terminal B transmits $X_D F(1)$ that is the re-constructed symbol by DF protocol [1]. Especially, in time slot 5, $X_D F^*(4)$ means that the terminal B transmits conjugation of the re-constructed symbol. The transmitted symbols in time slots 4 and 5 have a channel diversity effects using the STBC [3]. Basically, the power of the transmitted symbols in second, third, fourth and fifth time slot is already normalized by $1/\sqrt{2}$ because the total transmit power of cooperation-mode is the same as that of non-cooperative communication. Therefore, the terminal uses less power than non-cooperative communication.

IV. DECODING METHOD OF PROPOSED SCHEME

In order to decode the transmitted symbols a decoding scheme suitable for the proposed transmission structure is proposed in this section. Decoding scheme is carried out at the destination using received symbols. The transmitted symbols in the terminal A and the terminal B undergo the channel and arrive at the destination in the form of superposition. It is assumed that the channel is constant for the five time slots. So, the received symbols $Y^A(i), i = 1, 2, 3, 4, 5$ can be expressed as following equations,

$$\mathbf{Y}^A(1) = \mathbf{H}_1^A \mathbf{X}^A(1) + \mathbf{W}(1), \tag{5}$$

$$\mathbf{Y}^A(2) = \mathbf{H}_1^A \mathbf{X}^A(2) + \mathbf{H}_2^A \mathbf{X}_{DF}^A(1) + \mathbf{W}(2), \tag{6}$$

$$\mathbf{Y}^A(3) = \mathbf{H}_1^A \mathbf{X}^A(3) + \mathbf{H}_2^A \mathbf{X}_{DF}^A(2) + \mathbf{W}(3), \tag{7}$$

$$\mathbf{Y}^A(3) = \mathbf{H}_1^A \mathbf{X}^A(4) + \mathbf{H}_2^A \mathbf{X}_{DF}^A(3) + \mathbf{W}(4), \tag{8}$$

$$\mathbf{Y}^A(4) = -\mathbf{H}_1^A \mathbf{X}^A(3)^* + \mathbf{H}_2^A \mathbf{X}_{DF}^A(4)^* + \mathbf{W}(5), \tag{9}$$

where H_1^A is the channel between the terminal A and the destination, H_2^A is the channel between the terminal B and the destination and $W(i), i = 1, 2, 3, 4, 5$ is the AWGN. The received signals in the destination are decoded in three steps. In the first step, because the transmission structure in the time slot 4 and 5 is the conventional STBC, $X(3)$ and $X(4)$ are estimated by using the conventional STBC decoding algorithm [3]. $X(3)$ and $X(4)$ are estimated as following equations,

$$\hat{\mathbf{X}}(3) = \frac{(\hat{\mathbf{H}}_2^A)^* \mathbf{Y}(4) - (\hat{\mathbf{H}}_1^A)^* \mathbf{Y}^*(5)}{(\hat{\mathbf{H}}_1^A)^2 + (\hat{\mathbf{H}}_2^A)^2}, \tag{10}$$

$$\hat{\mathbf{X}}(4) = \frac{(\hat{\mathbf{H}}_1^A)^* \mathbf{Y}(4) + (\hat{\mathbf{H}}_2^A)^* \mathbf{Y}^*(5)}{(\hat{\mathbf{H}}_1^A)^2 + (\hat{\mathbf{H}}_2^A)^2}, \tag{11}$$

where $\hat{H}_1$ is estimated channel between the terminal A and the destination, and $\hat{H}_2$ is estimated channel between the terminal B and the destination. In the second step, $X(1)$ is estimated by using (5) similar to the conventional single input single output (SISO) system. $X(1)$ is estimated to equalize the channel H_1. In the third step, $X(2)$ is estimated by using maximum ratio combining (MRC) [5] with successive interference cancellation (SIC). By using the estimated $\hat{X}(1)$ and $\hat{X}(3)$ in the first and second step, $\tilde{Y}(2)$ and $\tilde{Y}(3)$ are derived as follows,

$$\tilde{\mathbf{Y}}(2) = \mathbf{Y}(2) - \hat{\mathbf{H}}_2^A \hat{\mathbf{X}}(1), \tag{12}$$

$$\tilde{\mathbf{Y}}(3) = \mathbf{Y}(3) - \hat{\mathbf{H}}_1^A \hat{\mathbf{X}}(3), \qquad (13)$$

where $\hat{X}(1)$ and $\hat{X}(3)$ are the estimated symbols in the first and second step. By using the estimated $\hat{X}(1)$ and $\hat{X}(3)$ in the first step and the estimated $\hat{H}_1^A$ and $\hat{H}_2^A$, $X(1)$ and $X(3)$ are cancelled from received symbol $Y(2)$ and $Y(3)$. So $\tilde{Y}(2)$ and $\tilde{Y}(3)$ can be represented as following equations,

$$\tilde{\mathbf{Y}}(2) = \hat{\mathbf{H}}_1^A \hat{\mathbf{X}}(2) + \mathbf{W}(2), \qquad (14)$$

$$\tilde{\mathbf{Y}}(3) = \hat{\mathbf{H}}_2^A \hat{\mathbf{X}}(2) + \mathbf{W}(3). \qquad (15)$$

In (14) and (15), $X(2)$ gets a channel diversity effects by the channel H_1^A and H_2^A. Therefore, MRC decoding algorithm is used to estimate $X(2)$ with maximum channel diversity effects.

V. PERFORMANCE EVALUATION AND DISCUSSION

In this section, the proposed scheme is evaluated in terms of BER and throughput. To confirm the theoretical performance, it is assumed that the channel is estimated perfectly at the receiver. The proposed scheme can be applied to any system. In this paper, the proposed scheme is applied to the OFDM that is used actively in recent years. The number of FFT length is 256-points and the number of guard interval(GI) length is 16-points in the OFDM. Modulation scheme is quadrature phase shift keying (QPSK) without channel coding. The channel is modeled by 8-paths Rayleigh fading channel. Fig. 2 shows a BER performance comparison of the conventional [2] and the proposed scheme. It is shown that the proposed scheme produces almost the same performance as the conventional scheme. It is remarked that the proposed scheme increases the throughput. Fig. 3 shows a throughput comparison of the conventional [2] and the proposed scheme. The throughput is defined as following equation,

$$T = (1 - R) \times T_r \times N, \qquad (16)$$

where T is the throughput, R is the BER value, T_r is the transmission rate and N is the bit length per one time slot. So, the throughput T is the number of transmission success-bits per one phase time. In the Fig. 3, the throughput of the proposed scheme is about 15[bpp] higher than the conventional scheme because of increased transmission rate.

VI. CONCLUSION

The cooperative communication is an attractive scheme to increase the reliability and decreases the throughput. Therefore, even though a scheme to increase throughput is needed, only a few researches have been performed to date. In this paper, the novel transmission structure is proposed to increase the throughput. It is remarked that the throughput of the proposed scheme is higher than the conventional scheme. Therefore, the cooperative communication using the proposed scheme can serve the high throughput.
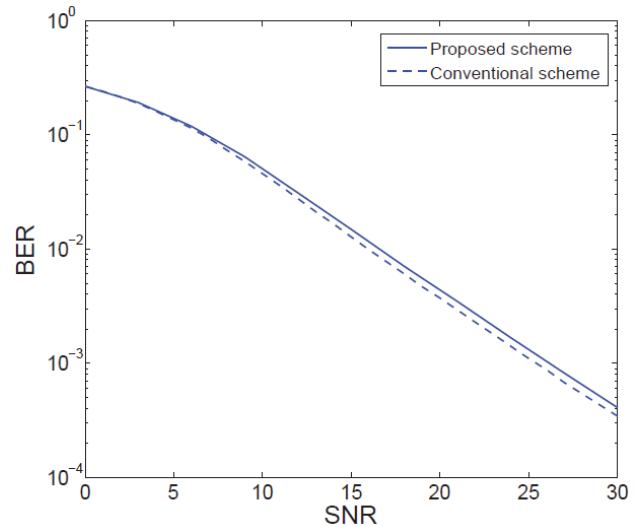

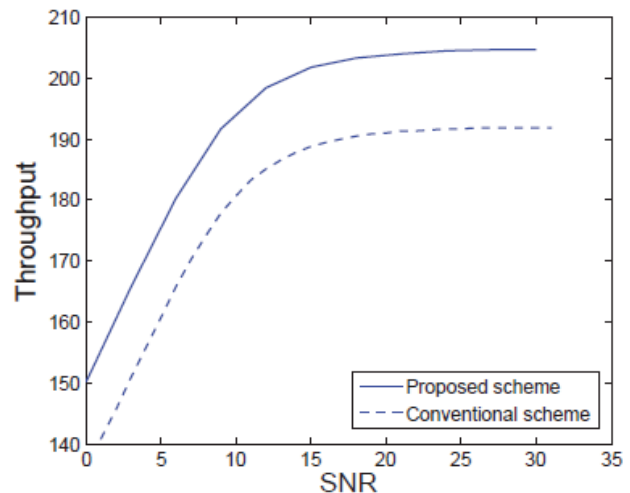Fig. 2.   The BER performance comparison of the conventional and the proposed scheme

Fig. 3.   The throughput comparison of the conventional and the proposed scheme

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