Cyclic Path Switching for Lattice Reduction-aided Iterative Linear Receivers in Overloaded MIMO Systems

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Abstract: This paper proposes a technique called “Cyclic path switching (CPS)” to improve the transmission performance of iterative linear receivers assisted with the lattice reduction in overloaded MIMO channels. The proposed CPS applies different parameters to the LLL algorithm, one of algorithms for the lattice reduction, in order to prepare two paths in the iterative linear receivers. The CPS cyclically switches the paths in the iteration process of the receiver, which is expected to randomize error bits and to improve the decoding performance in the proposed receiver. The CPS enables the iterative receiver to attain a gain of about 0.5dB at the packet error rate (PER) of 10^{-2} in a 6×2 MIMO system with the 64 QAM, when the reception process is iterated 50 times, even though the CPS is implemented with little additional computational complexity.

Keywords: Overloaded MIMO, Lattice reduction, Quadrature Amplitude Modulation, Iterative Reception

Classification: Wireless communication technologies

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1 Introduction

Higher user throughput is demanded as well as higher capacity in wireless communication systems. Multiple-Input-Multiple-Output (MIMO) spatial multiplexing has been applied to wireless local area networks (WLANs) or cellular systems to comply with the demand. Because terminals usually do not have enough space to put many antennas on themselves, the user throughput is limited by the number of antennas on a terminal in downlinks. Although multi-user MIMO can increase the network throughput in downlinks despite of the limit, multi-user MIMO can not increase the user throughput. Overloaded MIMO has been investigated to overcome the limit. Because more signal streams than the number of receive antennas are allowed to transmit simultaneously in overloaded MIMO systems, terminals are imposed to detect those signal streams with few antennas. Non-linear receivers have been investigated for the signal demodulation [1]. Non-linear receivers combined with channel decoding have been considered for performance enhancement. However, such non-linear receivers are quite difficult to apply to terminals because of its prohibitive high computational complexity. Complexity reduction techniques have been proposed for non-linear receivers [2, 3]. Iterative linear receivers have been proposed for further complexity reduction [4]. Such linear receivers make it easier to apply quadrature amplitude modulations (QAMs) that play an important role in high speed wireless communications. While the performance of the linear receivers is improved as the signal reception is iterated, error bit randomization is shown to enhance the transmission performance [5].

This paper proposes a technique called “Cyclic path switching (CPS)” to improve the transmission performance of iterative linear receivers assisted with the Lenstra–Lenstra–Lovász (LLL) algorithm, one of algorithms to implement the lattice reduction. The proposed CPS prepares two paths with different parameters. The two paths are switched during the iteration of the signal reception. The switching is expected to randomize error bits, which improves the decoding performance.

2 Iterative linear receivers for overloaded MIMO

We assume that a transmitter on an access point or a base station transmits N_T spatially multiplexed signal streams from N_T antennas without any precoding. Those signals are received at a receiver on a terminal with N_R antennas. Because the number of installable antennas on a terminal is limited, the number of the antennas on a terminal N_R is less than that of antennas on a base station N_T . For high speed transmission, QAMs are applied. Information bit sequence is encoded and the encoded bits are provided to a QAM modulator. Let $\mathbf{X} \in \mathbb{C}^{N_T}$ denote a transmission signal vector where the N_T modulation signals are included as entries, a received signal $\mathbf{Y} \in \mathbb{C}^{N_R}$ can be

written as,

$$\mathbf{Y} = \mathbf{H}\mathbf{X} + \mathbf{N}, \quad (1)$$

where $\mathbf{H} \in \mathbb{C}^{N_R \times N_T}$ and $\mathbf{N} \in \mathbb{C}^{N_R}$ represent a channel matrix between the transmitter and the receiver and an additive white Gaussian noise (AWGN). We apply the iterative linear receiver for the signal detection [4]. Let $\underline{\mathbf{Y}} \in \mathbb{C}^{(N_R+N_T)}$ denote an extended received signal vector defined as $\underline{\mathbf{Y}} = \begin{pmatrix} \mathbf{Y}^T & \mathbf{0}_{N_T}^T \end{pmatrix}^T$ where superscript T and $\mathbf{0}_{N_T}$ denote transpose of a vector or matrix and the N_T dimensional null vector. The iterative receiver updates the received signal vector as follows.

$$\underline{\mathbf{Y}}^{(n)} = \underline{\mathbf{Y}} + \begin{pmatrix} \mathbf{O} \\ \frac{\sigma}{\sigma_d} \bar{\mathbf{X}}^{(n)} \end{pmatrix} \quad (2)$$

In (2), $\underline{\mathbf{Y}}^{(n)} \in \mathbb{C}^{N_R+N_T}$ and $\bar{\mathbf{X}}^{(n)} \in \mathbb{C}^{N_T}$ denote an updated received signal vector and a replica of the transmission signal vector made from the channel decoder output bits at the n th iteration. In addition, σ and σ_d denote the standard deviation of the AWGN and that of the modulation signal. The updated received signal vector is fed to a linear signal detector assisted with the LLL algorithm and the detector output vector is fed to a lattice point searchers where the nearest lattice points of elements in the input vector are searched. The lattice point searcher output vector is transformed with a unimodular matrix given by the LLL and the transformed vector is provided to a hard-input-hard-output (HIHO) channel decoder via demappers and deinterleavers. As is described above, the HIHO decoder output signals are fed back to the received signal update as $\bar{\mathbf{X}}^{(n)}$ via mappers and interleavers.

3 Cyclic path switching

It is well known that the decoding performance is deteriorated if burst errors are input to channel decoders. Though bit interleavers are used for reduction of burst errors in the iterative receiver, the signals are simply passing through the same interleaver during the iteration process. This paper proposes a technique to randomize the signals in the iteration process to mitigate the performance degradation caused by burst errors. The proposed technique utilizes a unimodular matrix for the randomization. The unimodular matrix $\mathbf{T}^{(n)} \in \mathbb{C}^{N_T \times N_T}$ is used at the n th iteration stage as follows [4].

$$\mathbf{X}^{(n)} = \mathbf{T}^{(n)} \text{sic} \left[\left(\bar{\mathbf{Q}}^{(n)} \right)^H \underline{\mathbf{Y}}^{(n)} \right] \quad (3)$$

In (3), superscript H, $\mathbf{X}^{(n)}$, $\bar{\mathbf{Q}}^{(n)}$, and $\text{sic}[\mathbf{V}] \in \mathbb{C}^{N_T}$ represent Hermite transpose of a vector or a matrix, a demodulated transmission signal vector, an orthogonal matrix where the column vectors are orthonormal each other at the n th iteration stage, a serial interference canceler (SIC) output vector with an input vector $\mathbf{V} \in \mathbb{C}^{(N_R+N_T)}$. The unimodular matrix $\mathbf{T}^{(n)}$ and the orthogonal matrix $\bar{\mathbf{Q}}^{(n)}$ are given by the LLL algorithm with the channel matrix $\mathbf{H}$.

As is shown in (3), the unimodular matrix transforms the SIC output vector. If different unimodular matrices are applied stage by stage in the iterative reception, the SIC output vector is transformed differently. The use of different unimodular matrices is expected to randomize the errors in the SIC output vector. The different unimodular matrices can be obtained with different δ values, because characteristics of a unimodular matrix is determined by the δ value in the LLL algorithm. In this paper, two values such as δ_1 and δ_2 are used to obtain two unimodular matrices $\mathbf{T}_1$ and $\mathbf{T}_2$, respectively. The two unimodular matrices are applied in the iterative reception as follows.

$$\mathbf{T}^{(n)} = \begin{cases} \mathbf{T}_1 & (\text{mod}(n, N_S) = 0) \wedge (n \leq N_L) \\ \mathbf{T}_2 & \text{otherwise} \end{cases} \quad (4)$$

In (4), $N_L \in \mathbb{R}$ and $N_S \in \mathbb{R}$ are a window length when the two unimodular matrices are switched and a switching cycle, respectively. The LLL enables detectors to achieve better transmission performance as the δ value gets close to one in general. Because the unimodular matrix $\mathbf{T}_1$ is used periodically only when n is less than N_L , the transmission performance is dominated by the unimodular matrix $\mathbf{T}_2$. Hence, we apply a bigger value to δ_2 for superior transmission performance. A smaller value is set to δ_1 , because errors can be more randomized as δ_1 is set more apart from δ_2 . The configuration of the CPS is illustrated in Fig. 1 where the δ_1 and the δ_2 are used in the upper and the lower paths, respectively. Though the two paths are illustrated for easy understanding of the CPS, additional complexity needed for the CPS is only to obtain one more unimodular matrix in every packet.

Fig. 1. Configuration of cyclic path switching

4 Simulation

We evaluate the performance of the CPS in an overloaded MIMO channel by computer simulation. The number of transmit antennas N_T and that of received antennas N_R are 6 and 2, respectively. Because the number of the

spatially multiplied streams is the same to that of the transmit antennas N_T , the overloading ratio is 3. Block Rayleigh fading based on the Jakes' model is applied as a channel model where the Doppler frequency is zero in a packet duration. The channel impulse responses are independent and identically distributed in all the channels. The half rate convolutional code with constraint length of 3 and block interleavers are used. A single carrier modulation with the 64QAM is applied. The channel estimation is perfect. The parameter setting of $N_c = 50$, $N_L = 20$, and $N_S = 10$ is applied. Because the δ has to be set as $1 < \delta < 0.5$ in the complex LLL algorithm, $\delta_1 = 0.51$ and $\delta_2 = 0.9$ are applied to the CPS due to the reason described above. This means that the signals pass through the path with $\delta_1 = 0.51$ only at the 10th and 20th iteration stages, according to (4).

4.1 Convergence property of CPS

Figure 2 shows the convergence performance of the iterative receiver with the CPS in terms of the packet error rate (PER). The horizontal axis means the number of the iterations. In the figure, the convergence performance of the receiver without CPS is added as a reference. The E_b/N_0 is set to 54dB. The PER of the two receivers falls smoothly as the number of the iteration increases from 0 to 9. While the PER of the receiver without the CPS converges gradually after that, the PER of the receiver with the CPS suddenly gets worse at the 10th iteration stage, since the signals pass through the path with $\delta_1 = 0.51$ at the stage which is worse than the other. Because the path is switched back to the original after the switching, the PER performance dropped at the 11th iteration stage. Even though the path is kept same until the 2nd path switching at the 20th iteration stage, the better PER and the worse PER appear by turn as the reception is iterated. The similar zigzag PER performance can also be seen after the second path switching. Anywhere, the PER performance of the receiver with the CPS is better than that without CPS. When the path is switched at the even times iteration, the better PER can be obtained at the even times iteration after the switching. If we make use of the fact, we can achieve better performance.

4.2 PER v.s. E_b/N_0

The PER performance of the receiver with the CPS is evaluated with respect to E_b/N_0 in Fig. 3. The performance of the receiver without CPS is also added for comparison. While the CPS attains a small gain when the PER is about 10^{-1} , the CPS achieves a bigger gain as the E_b/N_0 rises. The CPS achieves about 0.5dB better transmission performance at the PER of 10^{-2} . Such a gain is obtained in spite of the E_b/N_0 , as long as the E_b/N_0 is greater than 51dB.

5 Conclusion

This paper has proposed a technique called ‘‘Cyclic path switching (CPS)’’ to improve the transmission performance of iterative linear receivers assisted

Fig. 2. PER convergence property of decoder output stream

Fig. 3. PER performance of cyclic path switching

with the lattice reduction in overloaded MIMO channels. The CPS randomizes signals input to the decoder of the receiver, which makes the decoder achieves better transmission performance. Even though the CPS can be implemented with little additional computational complexity, the CPS attains a gain of about 0.5dB at the packet error rate (PER) of 10^{-2} in a 6×2 overloaded MIMO system with the 64 QAM, when the reception process is iterated 50 times. Since a gain of 0.5dB is remarkable in the field of error correction coding, the CPS that improves the decoding performance with negligible small additional complexity, is worth introducing in the system.

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