LETTER

Iterative FDIC Using 2D-MMSE FDE for Turbo-Coded HARQ in SC-MIMO Multiplexing

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SUMMARY Multiple-input multiple-output (MIMO) multiplexing is an attractive technique to achieve very high-speed transmission with a limited bandwidth. Recently, we proposed an iterative frequency-domain interference cancellation (FDIC) for single-carrier MIMO (SC-MIMO) multiplexing. In our previous work, assuming that the interference from the other antennas can be perfectly cancelled in FDIC, one-dimensional minimum mean square error (1D-MMSE) frequency-domain equalization (FDE) was used. However, the residual interference remains after performing FDIC. In this paper, to improve the transmission performance with iterative FDIC, we replace 1D-MMSE FDE by 2D-MMSE FDE, which takes the residual interference from the other antennas after FDIC into account. We investigate, by computer simulation, the throughput performance of rate compatible punctured turbo coded hybrid ARQ (RCPT-HARQ) with MIMO multiplexing in a frequency-selective Rayleigh fading channel.

key words: *single-carrier, MIMO, iterative cancellation, MMSE, ARQ*

1. Introduction

Recently, multiple-input multiple-output (MIMO) multiplexing [1] has been attracting much attention to achieve very high-speed data transmission in a band-limited mobile radio channel [2]. Broadband wireless packet access will be the core technology of the next generation mobile communication systems. For achieving very high-speed and high-quality packet transmission with a limited bandwidth, the joint use of MIMO multiplexing and hybrid ARQ (HARQ) is effective. In MIMO multiplexing, accurate signal separation/detection is required because a superposition of all transmitted signals is received at the receiver. When MMSE separation/detection is applied in MIMO multiplexing, an MMSE weight, which considers both transmit and receive antennas, is used. We call it two-dimensional (2D)-MMSE weight. On the other hand, in single-input multiple-output (SIMO) transmission, which is the case of single antenna transmission with antenna diversity reception, MMSE weight which considers the receive antennas can be used. We call it 1D-MMSE weight.

Recently, we proposed iterative frequency-domain interference cancellation (FDIC) for single-carrier MIMO (SC-MIMO) multiplexing in a frequency-selective fading channel [3], [4]. In [3] and [4], a series of FDIC and minimum mean square error frequency-domain equalization (MMSE FDE) is repeated a sufficient number of times. In our previous work, assuming that the interference from other antennas is sufficiently reduced by interference cancellation, the MIMO channel seen after interference cancellation is regarded as the SIMO channel. Therefore, 1D-MMSE weight is used in an iterative process. However, the interference from other antennas actually remains even if the interference cancellation is used and this residual interference limits the performance improvement. We expect that the use of 2D-MMSE weight provides higher accuracy of signal separation. In this paper, to improve the transmission performance with iterative FDIC, we replace 1D-MMSE FDE by 2D-MMSE FDE, which takes the residual interference from the other antennas into account, and updates the 2D-MMSE weight in each signal detection. We evaluate, by computer simulation, the throughput performance of rate compatible punctured turbo coded (RCPT)-HARQ [5], [6] with SC-MIMO multiplexing using the proposed scheme in a frequency-selective Rayleigh fading channel.

The remainder of this paper is organized as follows. Section 2 describes 2D-MMSE FDE in the iterative FDIC. Section 3 presents the computer simulation results of the HARQ throughput performances. Section 4 concludes this paper.

2. Iterative FDIC Using 2D-MMSE FDE

Before describing iterative FDIC using 2D-MMSE FDE, the transmission system model is given. Then, 2D-MMSE FDE weight is presented.

2.1 Transmission System

We consider SC-(N_t, N_r) MIMO multiplexing, where N_t and N_r denote the numbers of transmit antennas and receive antennas. In this paper, type II RCPT-HARQ S-P8 [6] is considered. After bit-interleaving and data-modulation, the data-modulated symbol sequence is serial-to-parallel (S/P) converted to N_t parallel sequences, each to be transmitted from a different transmit antenna. After inserting the GI per N_c-symbol block, N_t data blocks are transmitted simultaneously in parallel from N_t transmit antennas using the same carrier frequency.

Figure 1 shows the receiver structure. At the receiver, after the removal of the GI from the received signal, N_c-point fast Fourier transform (FFT) is applied to decompose the GI-removed received signal into N_c frequency components. The kth frequency component $R_{n_r}(k)$ of the signal

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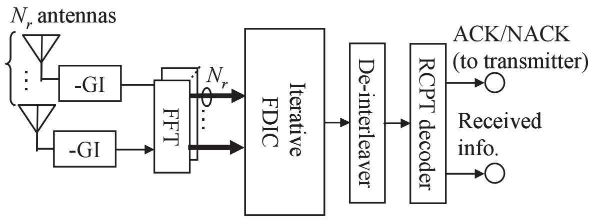

Fig. 1 Receiver structure.

received on the n_rth antenna can be expressed as

$$R_{n_r}(k) = \sqrt{2S}\sum_{n_t=0}^{N_t-1} H_{n_r,n_t}(k)S_{n_t}(k) + \Pi_{n_r}(k), \tag{1}$$

where S is the received signal power per antenna, $H_{n_r,n_t}(k)$ is the complex channel gain between the n_tth transmit antenna and the n_rth receive antenna, $S_{n_t}(k)$ is the kth frequency component of the data block transmitted from the n_tth antenna, and $\Pi_{n_r}(k)$ is the noise component. Then, FDIC using 2D-MMSE FDE is carried out, followed by N_c-point IFFT, log-likelihood ratio (LLR) computation for RCPT decoding and error detection. The result of error detection is fedback to the transmitter as ACK/NACK.

2.2 Iterative FDIC

In this paper, two types of FDIC are considered: parallel FDIC and successive FDIC. The ith iteration is described below. In parallel FDIC, the signal detection is carried out for all the transmitted blocks in parallel. The parallel FDIC operation in order to extract the received signal $\hat{R}^{(i)}_{n_r,n_t}(k)$ transmitted from the n_tth antenna is represented as

$$\hat{R}^{(i)}_{n_t,n_r}(k) = R_{n_r}(k) - \sqrt{2S}\sum_{n_t'=0\neq n_t}^{N_t-1} H_{n_r,n_t'}(k)\hat{S}^{(i-1)}_{n_t'}(k), \tag{2}$$

where $\{\hat{S}^{(i-1)}_{n_t'}(k);\ k\text{=}0\text{–}N_c-1\}$ is the n_t'th frequency-domain symbol replicas generated by feeding back the $(i-1)$th iteration result.

On the other hand, in the successive FDIC, the signal detection is performed according to the descending order of the reliability. In this paper, the signal, which has the highest equivalent channel gain among the undetected signals, is detected. The equivalent channel gain $\hat{H}^{(i)}_{n_t}$ of the n_tth transmit antenna at the ith iteration can be obtained from [7]

$$\hat{H}^{(i)}_{n_t} = \sum_{k=0}^{N_c-1}\sum_{n_r=0}^{N_r-1} w^{(i)}_{n_r,n_t}(k)H_{n_r,n_t}(k), \tag{3}$$

where $w^{(i)}_{n_r,n_t}(k)$ is the 2D-MMSE weight for the n_rth receive antenna in order to detect the signal transmitted from the n_tth transmit antenna (the computation of 2D-MMSE weight will be explained in Sect. 2.3). Without loss of generality, the transmit antenna having the highest equivalent channel gain is assumed to be the 0th transmit antenna, followed by the 1st, 2nd, ..., (N_t-1)th antennas. The successive FDIC operation in order to extract the received signal $\hat{R}^{(i)}_{n_t,n_r}(k)$ transmitted from the n_tth antenna is represented as

$$\hat{R}^{(i)}_{n_t,n_r}(k) = R_{n_r}(k) - \sqrt{2S}\left\{\begin{array}{l}\displaystyle\sum_{n_t'=0}^{n_t-1} H_{n_r,n_t'}(k)\hat{S}^{(i)}_{n_t'}(k)\\ \displaystyle+\sum_{n_t'=n_t+1}^{N_t-1} H_{n_r,n_t'}(k)\hat{S}^{(i-1)}_{n_t'}(k)\end{array}\right\}. \tag{4}$$

Since the blocks with $n_t' < n_t$ have been detected, their replicas (i.e., $\hat{S}^{(i)}_{n_t'}(k)$) are generated using the decision feedback of the present ith iteration result. However, the blocks with $n_t' > n_t$ are undetected. Therefore, their replicas (i.e., $\hat{S}^{(i-1)}_{n_t'}(k)$) are generated using the decision feedback of the $(i-1)$th iteration result.

2.3 Obtaining 2D-MMSE FDE Weight

The kth frequency component $\tilde{R}^{(i)}_{n_t}(k)$ of the n_tth block after 2D-MMSE FDE is given as

$$\tilde{R}^{(i)}_{n_t}(k) = \boldsymbol{w}^{(i)}_{n_t}(k)\hat{\boldsymbol{R}}^{(i)}_{n_t}(k), \tag{5}$$

where $\hat{\boldsymbol{R}}^{(i)}_{n_t}(k) = [\hat{R}^{(i)}_{n_t,0}(k),\cdots,\hat{R}^{(i)}_{n_t,N_r-1}(k)]^T$ is the N_r-by-1 received signal vector after the FDIC associated with the signal transmitted from the n_tth antenna and $\boldsymbol{w}^{(i)}_{n_t}(k) = [w^{(i)}_{0,n_t}(k),\cdots,w^{(i)}_{N_r-1,n_t}(k)]$ is the 1-by-N_r 2D-MMSE weight vector for the n_tth antenna.

The MMSE weight minimizes the mean square error $E\left[|e(k)|^2\right]$ between the signal transmitted from the n_tth antenna and the FDIC output after performing FDE, where $e(k)$ is defined as

$$e(k) = \sqrt{2S}S_{n_t}(k) - \boldsymbol{w}^{(i)}_{n_t}(k)\hat{\boldsymbol{R}}^{(i)}_{n_t}(k). \tag{6}$$

We can show that $\boldsymbol{w}^{(i)}_{n_t}(k)$ is given as

$$\boldsymbol{w}^{(i)}_{n_t}(k) = \boldsymbol{H}^H_{n_t}(k)\left[\boldsymbol{H}(k)\boldsymbol{G}^{(i)}_{n_t}\boldsymbol{H}^H(k) + \left(\frac{E_s}{N_0}\right)^{-1}\boldsymbol{I}_{N_r}\right]^{-1}, \tag{7}$$

where E_s/N_0 $(= ST_s/N_0)$ represents the average received symbol energy-to-AWGN power spectrum density ratio, $\boldsymbol{I}_{N_r}$ is the N_r-by-N_r identity matrix, and $(.)^H$ is the Hermitian transpose operation. $\boldsymbol{H}(k)$ is the N_r-by-N_t complex channel gain matrix and $\boldsymbol{H}_{n_t}(k)$ is the n_tth column vector of $\boldsymbol{H}(k)$. $\boldsymbol{G}^{(i)}_{n_t} = diag[g^{(i)}_0,\cdots,g^{(i)}_{n_t'},\cdots,g^{(i)}_{N_t-1}]$ is an N_t-by-N_t diagonal matrix which represents the impact of the residual interference from other antennas after FDIC and ISI. $g^{(i)}_{n_t'}$ corresponds to the average interference power.

For the parallel FDIC, $g^{(i)}_{n_t'}$ is given by

$$g^{(i)}_{n_t'} = \begin{cases} 1, & \text{if } n_t' = n_t \\ \dfrac{1}{N_c}\displaystyle\sum_{t=0}^{N_c-1}\{|\check{s}^{(i-1)}_{n_t'}(t)|^2 - |\hat{s}^{(i-1)}_{n_t'}(t)|^2\}, & \text{if } n_t' \neq n_t \end{cases}, \tag{8}$$

where $\check{s}^{(i-1)}_{n_t'}(t)$ is the hard replica of the symbol block $\{s_{n_t'}(t)\}$

transmitted from the n_t'th antenna and $\hat{s}_{n_t'}^{(i-1)}(t)$ is the soft replica of $\{s_{n_t'}(t)\}$. Both the hard and soft replicas are generated based on the feedback from the $(i-1)$th iteration result. Since the interference from other antennas is only cancelled, the ISI remains at FDIC outputs. Therefore, $g_{n_t}^{(i)} = E\left[\left|s_{n_t}(t)\right|^2\right] = 1$.

On the other hand, for the successive FDIC, $g_{n_t'}^{(i)}$ is given by

$$g_{n_t'}^{(i)} = \begin{cases} \dfrac{1}{N_c}\sum_{t=0}^{N_c-1}\left\{|\tilde{s}_{n_t'}^{(i)}(t)|^2 - |\bar{s}_{n_t'}^{(i)}(t)|^2\right\}, & \text{if } n_t' < n_t \\ 1, & \text{if } n_t' = n_t \\ \dfrac{1}{N_c}\sum_{t=0}^{N_c-1}\left\{|\tilde{s}_{n_t'}^{(i-1)}(t)|^2 - |\bar{s}_{n_t'}^{(i-1)}(t)|^2\right\}, & \text{if } n_t' > n_t \end{cases} . \tag{9}$$

In the case of 1D-MMSE FDE, we assume that the interference from other transmit antennas has been perfectly cancelled in the FDIC. Therefore, in both parallel and successive FDIC, the MMSE weight $\boldsymbol{w}_{n_t}^{(i)}(k)$ of 1D-MMSE FDE can be obtained with $g_{n_t}^{(i)} = 1$ and $g_{n_t'}^{(i)} = 0$, $n_t' \neq n_t$. 1D-MMSE FDE corresponds to the MMSE FDE for SIMO transmission case.

3. Computer Simulation

(4,4) MIMO multiplexing using 16QAM data modulation is considered. Coding rate R=1/3 turbo encoder, consisting of two (13,15) recursive systematic convolutional (RSC) encoders, is used. We assume that 4-by-4 channels are independent and frequency-selective block Rayleigh faded; each channel has a L=16-path uniform power delay profile with symbol-spaced time delays. Ideal channel estimation is assumed at the receiver. Each transmit block is composed of N_c=256 data symbols and a GI of N_g=32 symbols.

Figure 2 shows the throughput comparison between 2D-MMSE FDE and 1D-MMSE FDE. Since we have found that the use of three iterations (i=3) is enough to obtain a sufficient throughput improvement, only the throughput curves obtained with i=3 are plotted. It can be seen that 2D-MMSE FDE provides better throughput than 1D-MMSE FDE. This is because 2D-MMSE FDE can effectively suppress the residual interference from other antennas after FDIC. The required E_s/N_0 for achieving throughput of 10 bps/Hz is about 1 dB (1.6 dB) smaller with 2D-MMSE FDE than with 1D-MMSE FDE when parallel FDIC (successive FDIC) is used.

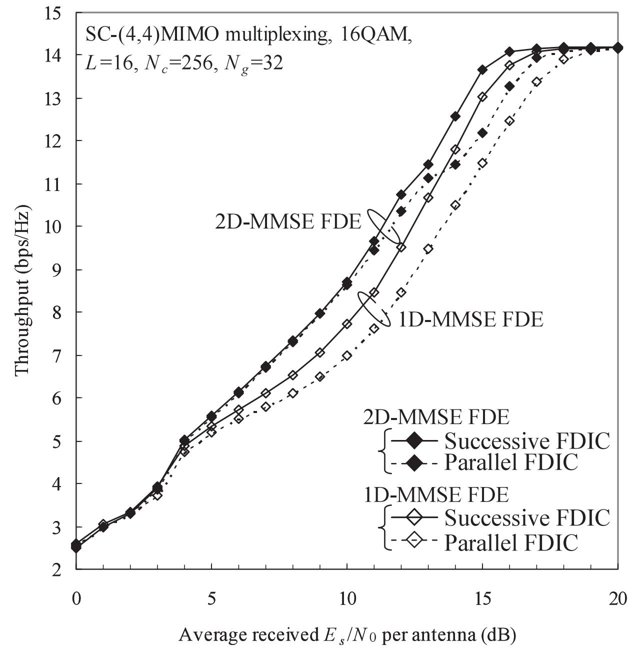

Fig. 2 Comparison between 2D-MMSE FDE and 1D-MMSE FDE.

4. Conclusions

We evaluated, by computer simulation, the throughput performance of SC-MIMO multiplexing with iterative FDIC using 2D-MMSE FDE in a frequency-selective Rayleigh fading channel. We have shown that 2D-MMSE FDE can provide better throughput performance than 1D-MMSE FDE. This is because the residual interference from other antennas after FDIC is suppressed more effectively by using 2D-MMSE FDE than by using 1D-MMSE FDE.

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